PREFACE TO THE ELEVENTH EDITION

The current edition of A CLASS-BOOK OF BOTANY is a much improved one. Improvements have been effected in the following directions: the whole text has been further revised, several portions, particularly of Morphology and Physiology, rewritten, Cryptogams and Gymnosperms enlarged, and many new sketches added. Another feature of the new edition is the incorporation of Gujarati and Marathi names of plants in the Appendix dealing with the glossary of Indian names of plants. It may be noted that A, B, G, H, M, M', O. P. T. and T' preceding Indian names of plants stand respectively for Assamese, Bengali, Gujarati, Hindi, Malayalam, Marathi, Oriya, Punjabi, Tamil and Telugu. The author believes that the book, as it stands now with its manifold improvements, will benefit a still wider circle of students.

For the suggestions and criticisms received from many teachers for the improvements effected in the current edition the author particularly expresses his deep sense of gratitude to Prof A. Das Gupta of Bangabasi College, Calcutta, Prof R. K. Sarkar of Asutosh College, Calcutta, Prof. S. Ghose of St Xavier's College, Calcutta, Prof K. S. Das of Surendranath College, Calcutta, Prof P. C. Das of Cotton College, Gauhati, Dr B. Samantarai of Ravenshaw College, Cuttack, and Prof B. K. Gowel of Ranbir College, Sangrur. Sincere thanks of the author are also due to all teachers in Botany who have taken a kindly interest in the book. The author also feels deeply indebted to Dr (Mrs) S. Chitaley of Government College of Science, Nagpur for kindly furnishing Gujarati names of plants, to Prof Y. B. Raje and his colleague Miss Tara W. Kelkar of S. P. College, Poona for Marathi names, and to Prof Hukamchand of P. U. College, Hoshiarpur for Punjabi names.

Satribari Road
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October, 1957

A. C. D.

PREFACE TO THE FIRST EDITION

This book, though intended primarily for the use of Intermediate and Medical students of Calcutta University and of the Dacca Board, covers somewhat wider grounds, and students of other universities, following the same or a slightly higher standard in the curricula, will find the book useful and instructive. Although the generally accepted methods of treatment have been followed, attention may be drawn to certain special features:

1. The text has been illustrated with numerous simple figures and explanatory diagrams drawn by the author himself in most cases directly from objects which are typical and easily available. The figures and diagrams have been drawn with a view to a correct and easy appreciation of them.

2. An attempt has been made to familiarize the students with the meanings of Latin and Greek prefixes and suffixes, and to trace the technical and scientific terms to their respective Latin and Greek roots. This will enable the students to master the subject of terminology more easily.

3. In many cases more than one example have been given to illustrate a particular form or feature. A laige number of English and vernacular names have been introduced to suit the convenience of students. Latin names have been followed by vernacular or English equivalents, or often by both.

The author takes this opportunity of thanking Dr D. Thomson. M.A., B.Sc. Ph.D.. I.E.S., Principal. Cotton College, Gauhati, for the encouragement received from him in the course of the preparation of this book. For some of the drawings the author expresses his thanks to his pupils, Madhab Chandra Das and Gour Mohan Das.

Cotton College
Gauhati, Assam
June 1929

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INTRODUCTION

1. **Botany.** The science that deals with the study of living objects goes by the general name of **biology** (*bios*, life; *logos*, discourse or science). Since both animals and plants are living, biology includes a study of both. Biology is, therefore, divided into two branches: **botany** (*botane*, herb) which treats of plants, and **zoology** (*zoon*, animal) which treats of animals.

2. **Scope of Botany.** The subject of Botany deals with the study of plants from many points of view. This science investigates the internal and external structures of plants, their functions in regard to nutrition, growth, movements and reproduction, their adaptations to the varying conditions of the environment, their distribution in space and time, their relationship with one another, their life-history, the laws involved in their evolution from lower and simpler forms to higher and more complex ones, the varied uses that plants may be put to, and lastly, the different methods that can be adapted to improve plants for better uses by mankind.

3. **Origin and Continuity of Life.** Life itself is mysterious, and its origin has still remained shrouded in mystery. It is, however, assumed that many millions of years ago life first came int [illegible] first; *pla* [illegible] a result [illegible] under a [illegible] the first- [illegible] ence its [illegible] generations with gradual changes of forms from simpler to more complex types of plants and animals extending over many millions of years, or, in other words, life is one continuous flow through many channels from the earliest and simplest [illegible]

[illegible] and plants have become so diversified through ages the proto-

plasm has remained constant in both. It is interesting to note the following facts: protoplasm is not formed afresh and, therefore, no new life comes into being or can be created; protoplasm is, however, continuous; and but for evolution life would have still remained in the first-formed, one-celled stage.

4. **Importance of Green Plants.** Green plants are essential for the existence of all kinds of life including even human life. Their importance in this respect lies, *firstly*, in the fact that they are the only mechanisms which are able to purify the atmosphere by absorbing carbon dioxide gas from it and releasing from their bo ... of water) an almost equal volume o ... *econdly*, the green plants prepare fc ... f constituent of rice, wheat, potato, ... ials—carbon dioxide obtained from the air, and water and inorganic salts obtained from the soil. Both these functions, viz., purification of the atmosph... and ... of food are the monopoly of green plant... are carried on by the green corpuscles or *chloroplasts* of the leaf during ... unlight being the source of energy. Animals being devoid of chloroplasts have no such power. It is evident, therefore, that animals including human beings are deeply indebted to plants for these basic needs, viz., oxygen f ... for nutrition. In these respects chloropl ... position so far as the livir ...

(5) **Uses of Plants.** ... threefold: food, clothing ... sively supplied by the p ... need of man is of course food. This food primarily comes from plants in the form of cereals (rice, wheat, maize, oat, rye and barley), millets (smaller grains), pulses, vegetables and fruits. For clothing again plants are indispensable. Their value as a source of fibres, coarse and fine, for the manufacture of garments can never be over-estimated. In this respect ... position supplemented by ... Flax is also ... eet an ever- ... plication of ... be of great importance for better utilization ... lucts. Then again shelter from the inclemencies of the weather and as a protection against natural enemy has been increasingly felt from time immemorial. In this respect the value of wood together with its mode of preservation has been found to be inestimable. Other products like bamboo, cane, reed, thatch

grass, etc., cannot be under-estimated in this connexion. With advance in civilization man's need is also ever on the increase. To meet this need he has tried to tap plants as sources for his comforts and varied uses by dint of his scientific knowledge and has been successful to a considerable extent. Thus a host of other useful products have been obtained from the plant world through his [illegible] this connexion spec[illegible] plant products: w[illegible] building, railway sleepers, fuel, etc.), oils (for lubrication, burning, soap-making, basis for paints, etc.), fibres (for gunny bag, rope, matting, carpet, canvas, etc.), drugs (for cure from diseases), dyes, paper, tannin, resin, gum, essential oil, rubber, alcohol, tea, coffee, cocoa, tobacco, spices, etc. Utility of many bacteria and [illegible] soil and various [illegible]ted. Last but not [illegible]ider drugs, called [illegible]lern times, which have come from the bacteria and fungi of the soil, for the treatment of severe types of infectious diseases. It is thus evident from the foregoing that a knowledge of botany and its proper application lead to the well-being of mankind in a variety of ways.

6. **Characteristics of Living Objects.** We do not know what life really is. It is something mysterious and we are not in a position to define it. All living objects have, however, certain characteristics by which they can be distinguished from the non-living. These characteristics are as follows:

(1) **Life-cycle.** All living objects follow a definite life-cycle of birth, growth, reproduction, old age and death. The animal or the plant develops from the **embryo** which again has its origin in a single cell known as the **egg-cell.** The embryo gradually grows into its characteristic form and size. In due course the adult plant or animal reproduces to maintain the continuity of the species and also to multiply in number. Ultimately the organism attains old age and dies.

(2) **Cellular Structure.** All living organisms are composed of characteristic types of structural units, called **cells.** A cell is an organized mass of living substance, called **protoplasm,** with a membrane surrounding it. In the case of plant cells but not of animal cells this membrane takes the [illegible] of a definite and distinct non-living wall, called the [illegible] This cellular structure is an exclusive feature of all [illegible] organisms.

(3) **Protoplasm.** Life cannot exist without protoplasm. It is the actual living substance in both plants and animals, and it is, as Huxley defined it, the physical basis of life. It carries on all the vital functions; it shows various kinds of movement and is sensitive to all kinds of stimuli such as light, temperature, chemical substance, electric shock, etc. It is a very delicate and complicated substance and any attempt to analyze it will destroy the properties that impart life to it, and kill it outright. Physically it is a hyaline, viscous substance and appears finely granular under the microscope. Chemically protoplasm is a highly complex mixture of proteins and a variety of other chemical compounds occurring in particular proportions and in particular patterns and interacting in a harmonious and consistent manner. The property we call life depends on the co-ordinated action of all these substances.

(4) **Respiration.** Respiration is a sign of life. All living beings—plants and animals—respire continuously day and night, and for the process of respiration they take in oxygen *gas* from the atmosphere and give out an almost equal volume of *carbon dioxide gas*. In plants this exchange of gases normally takes place through minute openings (see fig. 422) in the leaf. [illegible] .e. the energy [illegible] rials is release [illegible] toplasm for its manifold activities.

5. [illegible] animals and plants— posses [illegible] of giving rise to new young [illegible] objects have no such power [illegible] own into a number of irregular parts; but living objects follow certain definite periodic modes of reproduction, and give rise to the offspring of the same kind.

(6) [illegible] phenomenon of life. [illegible]

a spec [illegible]
to the [illegible]
the co [illegible]
in the [illegible]
in the formation of a variety of chemical substances.

(7) **Nutrition.** A living organism requires to be supplied with food. The chemical constituents of food are much the same in plants as in animals. These are ultimately digested

and assimilated by the protoplasm for its own nutrition and growth. A regular supply of food is thus an indispensable factor to the living organism.

(8) **Growth.** All living objects—plants and animals—grow. Non-living bodies may also grow, as does a crystal. But they differ in many respects. The growth of the non-living objects is external, i.e. new particles or molecules of the same physical and chemical nature are deposited on the external surface of their body from the surrounding medium and as a result they grow. In living objects, on the other hand, the growth is internal, i.e. it proceeds from within, new particles or molecules of different nature being secreted by the
[illegible] r of their body. There is only
[illegible] rowth. In living bodies the growth
[illegible] omplicated processes, both anabolic (constructive) and catabolic (destructive).

(9) ***Movements.*** Movements are commonly regarded as a sign of life. Movements in most plants are, however, restricted, being fixed to the ground: while most animals move freely. Moving plants and fixed animals are not, however, uncommon among the lower organisms. Movements in plants and animals may be *spontaneous* or *induced.*

(*a*) **Spontaneous movement** is the movement of an organism or of an organ of a plant or an animal *of its own accord,* i.e. without any external influence. This kind of movement is regarded as a characteristic sign of life. Spontaneous movement is evident in animals, and in plants it is exhibited by many unicellular algae, e.g. *Euglena* (see fig. 528), some filamentous algae, e.g. *Oscillatoria* (see fig. 526). Among the 'flowering' plants the best example of spontaneous movement is ex[illegible] H.
BAN-C[illegible] s of
proto[illegible] ants
are distinctly visible under the microscope.

(*b*) **Induced movement or irritability,** on the other hand, is the movement of living organisms or of their organs in response to external stimuli. Protoplasm is sensitive to a variety of external stimuli, and when a particular stimulus is applied the reaction is usually in the form of a movement. Thus when an animal burns itself it immediately moves away from the source of heat. When a green plant is grown in a closed chamber with an open window on one side, it grows and bends towards the source of light. In these cases heat and light act as stimuli, and living organisms respond to them

by [illegible] No such effect is produc[illegible] e a log of wood or a bar [illegible] uced movement are affo[illegible] H. [illegible] NARANGA—see fig. 504), tentacles of sundew (*Dro*[illegible] bend over the insect from all sides and entrap it, when it falls on the leaf. Similarly, the leaf-blade of Venus' fly-trap (see fig. 484), another carnivorous plant, closes suddenly, when an insect happens to touch it. Leaves of many plants again close up in the evening when the light fails and open again in the morning. This is spoken of as 'sleep' movement. Irritability is, however, more pronounced in animals than in plants.

7. **Differences between the Living and the Non-living.** It is very difficult to trace the absolute differences between the living and the non-living. Certain points may, however, be cited by way of general differences between the two. Protoplasm is the physical basis of life; so all objects containing protoplasm are regarded as living. Non-living objects are conspicuous by its absence. Thus the presence or absence of protoplasm makes a fundamental difference between the animate and the inanimate, and the various life-processes carried on by the protoplasm such as respiration, metabolism, nutrition, growth, movements and reproduction are only characteristics of the living objects. Non-living objects may, however, show movements and growth in a certain sense. Thus non-living objects like machines are seen to move when induced by external forces. Very minute particles embedded in a liquid are also seen to vibrate with great rapidity; this vibration is called **Brownian movement** as it was first observed by Robert Brown in 1828 while examining pollen grains under the microscope. Non-living objects like crystals and corals may also grow, but there is difference in the mode of growth between the living and the non-living, as already discussed. All nerves and tissues undergo fatigue on repeated stimulation from which they recover after a period of rest. Non-living objects like metals may also undergo similar fatigue when worked for a prolonged period, and these can be poisoned or stimulated by dru[illegible]d. Thus no[illegible]veen the livi[illegible]

[illegible] Higher and higher animals are readily distinguished from one

another by their possession of definite organs or members, particularly the organs of locomotion in the latter case, for the discharge of definite functions; but difficulty is experienced wh[illegible] d.
In [illegible] e-
tw [illegible] in
ge [illegible]

(1) **Growth.** The regions of growth are localized in the case of plants, lying primarily at the extremities—root-apex and stem-apex—and also in the interior, i.e. growth is both apical and intercalary; while in the case of animals growth is not localized to any definite regions, i.e. all parts grow simultaneously. Moreover, in plants growth proceeds until death; while in animals growth ceases long before death.

(2) **Chlorophyll.** Chlorophyll or the green colouring matter of leaves and tender shoots is highly characteristic of plants with the exception of fungi and total parasites. Chlorophyll is contained in special protoplasmic bodies, called plastids (see fig. 357), which often occur in large numbers in a cell. Chlorophyll and plastids are conspicuous by their absence in animal cells. Some animals may, however, turn green in colour by feeding upon green parts of plants.

(3) **Cell-wall.** Both plants and animals are cellular in co[illegible]
dis[illegible]
un[illegible]
pa[illegible]
ho[illegible]

(4) **Cellulose.** The cell-wall of the plant cell is made up [illegible]

(5) **Food.** Green plants absorb raw food materials from outside—water and inorganic salts from the soil and carbon dioxide from the air—and prepare organic food substances out of them, primarily in the leaf, with the help of chlorophyll in the presence of sunlight. Animals being devoid of chlorophyll have no power of manufacturing their own food. They have solely to depend on plants for this primary need. It is also to be noted that plants take in food in solution only, whereas animals can ingest solid food.

(6) **Utilization of carbon dioxide.** Plants possess the power of utilizing the carbon dioxide of the atmosphere.

It is only the green cells that have got this power. Thus during the daytime the green cells of the leaf absorb carbon dioxide from the surrounding air, manufacture sugar, starch, etc., and give out an almost equal volume of oxygen (by breakdown of water). Animals do not possess this power of utilizing the carbon dioxide or of manufacturing the food.

(7) **Movements.** Plants grow fixed to the ground or attached to some support, and as such they cannot bodily move from one place to another, except some lower types of plants; while animals move freely in search of food and shelter, and manoeuvre when attacked; some animals, of course, grow attached to some object.

(8) **Organs.** Various organs such as the organs of locomotion, respiratory organs, excretory organs, etc., have reached a stage of perfection in animals for efficient functioning; while in plants the corresponding organs are simple in construction or even altogether absent.

(9) **Ingestion of Food.** Plants cannot take in anything from outside except in solution; while animals can ingest solid food.

9. **Branches of Botany.** Botany, like every other science, may be studied from two aspects—the *pure* and the *applied* or *economic*. Pure botany deals with the study of plants as they form a part of nature, and applied botany as it is applied to the well-being of mankind. A comprehensive knowledge of the former is essential for the study of the latter; in fact pure botany forms the foundation for the study of applied botany at a later stage. Thus, to start with, we shall primarily confine ourselves to the study of pure botany. This may be divided into the following branches:

1. **Morphology** (*morphe*, form; *logos*, discourse or science). It deals with the study of forms and features of different plant organs such as roots, stems, leaves, flowers, seeds and fruits.

2. **Histology** (*histos*, a cobweb). The study of detailed structure of tissues making up the different organs of plants, as revealed by the microscope, is called ***histology***. The study of gross internal structure of plant organs by the technique of [illegible] asunder; *temnein*, to [illegible] the cell-structure with [illegible] the nucleus is a new established branch of histology.

3. **Physiology** (*physis*, nature of life). It deals with the various functions that the plants carry on. Functions may be *vital* or *mechanical*; vital functions are carried on by the living matter, i.e. the protoplasm, and the mechanical functions by certain dead tissues without the intervention of the protoplasm; as, for example, bark and cork protect the plant body, and certain hard tissues strengthen it. It is to be noted that structure and function are correlated, i.e. a particular structure develops in response to a particular function.

4. **Ecology** (*oikos*, house). It deals with the relationship that exists between an individual plant or a plant community and its surroundings.

5. **Plant Geography.** It deals with the distribution of plants over the surface of the earth and the factors responsible for such distribution.

6. **Taxonomy or Systematic Botany.** It deals with the description and identification of plants, and their classification into various natural groups according to the resemblances and differences in their morphological characteristics.

7. **Palaeobotany** (*palaios*, ancient). This deals with the ancient forms of plants preserved in the form of fossils in the earth's strata in past geological ages.

Applied or Economic Botany. This deals with the application of botanical knowledge to the well-being of mankind. It has also several branches: (*a*) agriculture dealing with the cultivation of field crops for food and industry; (*b*) [illegible] den plants for flowers and fr[illegible] iosis, cure and prevention of [illegible] the study of medicinal plant[illegible] rvation of drugs; (*e*) forestr[illegible] imber and other forest produ[illegible] s-breeding of plants evolving [illegible] d characteristics

10. **Divisions of the Plant Kingdom.** There are two main divisions of the plant kingdom, viz., **cryptogams** (*kryptos*, concealed; *gamos*, marriage) and **phanerogams** (*phaneros*, visible) Cryptogams are lower plants which never bear flowers or seeds (see Part V); while phanerogams are higher plants which always bear flowers and seeds; so cryptogams may be regarded as 'flowerless' or seedless' plants, and phanerogams as 'flowering' or 'seed-bearing' plants.

A. **Cryptogams.** The main groups of cryptogams from the lower types to the higher are the following:

I. **Thallophyta.** Thallophyta are lower crytogams in which the plant body is not differentiated into the root, stem

and leaf. Such an undifferentiated plant body is called a thallus and the word 'phyton' means plant—hence the term thallophyta or thallus-bearing plants. There are two groups of thallophyta: algae and fungi.

(*a*) **Algae** (sing. alga) are commonly green thallophyta containing chlorophyll although this colour may be masked by other colouring matters. They mostly grow in water and are of various forms. Common algae are pond-scum (B. SHAOLA), road-slime, sea-weed, etc.

(*b*) **Fungi** (sing. fungus) are non-green thallophyta containing no chlorophyll. They grow mostly on land either as parasites (see p. 42) or as saprophytes (see p. 45). Like algae they may be of various forms. Common examples of fungi are mould (B. CHHATA), mushroom (B. BANGER-CHHATA; H. BHUIN-PHOR), toadstool, puff-ball, etc.

2. **Bryophyta** are a group of higher cryptogams in which the plant body may be thalloid (primitive forms) or leafy (advanced forms). They develop some root-like structures, called rhizoids, but no true roots, and the conducting tissue is very simple and primitive. They grow on old damp walls, on moist ground and on bark of trees forming a sort of beautiful, green carpet and are more complicated and more advanced than the thallophyta. There are two groups of bryophyta: liverworts and mosses.

(*a*) **Liverworts** are thalloid bryophyta. Their body consists of a green flat dichotomously branched thallus with some rhizoids on its undersurface. Common examples are *Riccia* and *Marchantia*.

(*b*) **Mosses** are leafy bryophyta. Their body is differentiated into an axis (stem), leaves and some rhizoids. They are more advanced than liverworts. Common examples are *Funaria*, *Polytrichum*, etc.

3. **Pteridophyta** are highest cryptogams and include ferns and their allies. The plant body is differentiated into an underground horizontal stem (rhizome) or an erect stem, leaves and true roots, and the conducting tissues are well developed in it. Pteridophyta are much more complicated than bryophyta and differ from the 'flowering' plants in the fact that they do not produce flowers, fruits or seeds. They bear spores on their leaves by which they reproduce and multiply. They usually grow in moist shady places. Common groups and examples are the following:

(*a*) **Ferns.** Their young leaves coil like the tail of a dog, and mature leaves (sporophylls) bear spores on their undersurface. Common examples are *Pteris, Polypodium, Adiantum, Dryopteris, Nephrolepis,* etc.

(*b*) **Horsetails** (*Equisetum*). They produce short erect branches with whorls (circles) of small scale-like leaves. In them the spore-bearing leaves (sporophylls) are massed together in a cone on the top of the shoot and are arranged in whorls.

(*c*) **Club-mosses** (*Lycopodium* and *Selaginella*). They are trailing or creeping plants with very small leaves, and the sporophylls in them form into a cone at the apex of the shoot, as in *Equisetum*. In *Lycopodium* the leaves are commonly needle-like and spirally arranged on the branch, and the sporophylls also are spirally arranged in the cone; while in *Selaginella* the leaves (two kinds) are flat and arranged in four rows on the branch, and the sporophylls (two kinds) also are arranged in four rows in the cone.

B. **Phanerogams** or **spermatophytes.** These are 'flowering' or 'seed-bearing' plants. They constitute the highest division of the plant kingdom and have the largest number of species of all groups of plants. There are two main groups of phanerogams: gymnosperms and angiosperms.

1. **Gymnosperms** (*gymnos*, naked; *sperma*, seed) are naked-seeded plants, i.e. those in which the seeds are not enclosed in the fruit. They may be regarded as lower 'flowering' plants in which the flowers are unisexual (either male or female), simple in construction and primitive in nature. There are two main groups of gymnosperms: cycads and conifers.

(*a*) **Cycads** (*Cycas*, etc.). These are [illegible] plants with erect stout commonly [illegible] stem bearing a crown of fern-like [illegible] Flowers (male and female) are generally in the form of cones, [illegible] terminally on the main stem [illegible] In *Cycas* the male flower only forms into a cone. [illegible] two cotyledons. Cycads [illegible]

(*b*) **Conifers** (*Pinus*, [illegible] shrubs with often [illegible] small leaves (needle-like [illegible] are always in the form of [illegible] stem or branch [illegible] embryo is [illegible] the seeds [illegible] Conifers [illegible] type of [illegible]

2. **Angiosperms** (*angeion*, case) are closed-seeded plants, i.e. those in which the seeds are enclosed in the fruit. They may be regarded as higher 'flowering' plants in which the flowers are more complicated in construction and more advanced. Angiosperms are the highest forms of plants. There are two big groups of angiosperms: dicotyledons and monocotyledons.

(*a*) **Dicotyledons** are the bigger group of angiosperms in which the embryo of the seed bears *two* cotyledons, and the flower commonly bears *five* petals or multiple of this number.

(*b*) **Monocotyledons** are the smaller group of angiosperms in which the embryo of the seed bears only *one* cotyledon, and the flower commonly bears *three* petals or multiple of this number.

11. **Number of Species on Record**

1. Algae ..	... 20,000	species
2. Fungi ...	... 90,000	"
3. Mosses and allies ..	.. 22,700	"
4. Ferns and allies ...	... 10,000	"
5. Gymnosperms ...	... 700	"
6. Angiosperms (199,000)		
(*a*) Dicotyledons	... 159,000	"
(*b*) Monocotyledons	... 40,000	"
TOTAL	... 342,400	species

and raw food material from the roots to the leaves and that of prepared food material from the leaves to the storage organs also take place through the stem and the branches. Leaves are the lateral outgrowths of the stem or the branch, and each

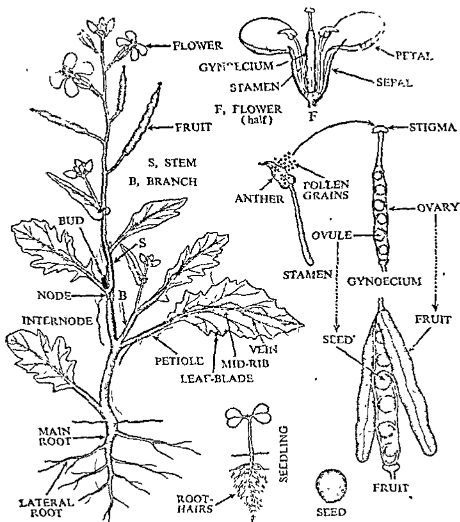


Fig. 1. Parts of an angiospermic plant (mustard plant)

leaf is provided with a stalk, called the **petiole**, and a flat green expanded portion, the **leaf-blade** (or **-lamina**), which is interspersed with numerous **veins** of which the median strong one is called the **mid-rib.** The leaf-blade being green in colour containing chlorophyll manufactures food, and is regarded as a very important vegetative organ. The stem and the branches are provided with **nodes** and **internodes** which are always absent from the root A **bud** appears in the axil of a leaf, and as it grows and elongates it gives rise to a branch. There is also a

bud at the apex of the stem or the branch, and it is responsible for elongation of that organ by its continued growth.

Reproductive Parts. The **flower** is a highly specialized reproductive shoot. Each typical flower consists of *four* distinct types of members arranged in *four* separate but closely set whorls or circles, one above the other, on the top of a long or short stalk. The lower two whorls are called *helping* or *accessory* whorls, and the upper two *essential* or *reproductive* whorls because only these two are directly concerned in reproduction. Of the two accessory whorls the first or the lowest one, often green in colour, is called **calyx,** and each member of it a **sepal.** The second whorl, often brightly coloured, is called **corolla,** and each member of it a **petal.** Initially both calyx and corolla give protection to the essential whorls at the bud-stage of the flower but later, as the flower opens, the calyx manufactures a little food, while the main function of the corolla is to attract insects from a distance by its bright colour. The third whorl of the flower or the first essential whorl is the male whorl, called **androecium** (*andros,* male), and each member of it a **stamen** or male reproductive organ. The fourth or the uppermost whorl of the flower or the second essential whorl is the female whorl, called **gynoecium** (*gyne,* female), and each member of it a **carpel.** Commonly the gynoecium is made up of one carpel or two to few carpels united together. Each stamen bears on its top a case, called the **anther,** which contains a mass of fine powdery or dust-like grains—the **pollen grains.** Each pollen grain bears a generative nucleus which later by a division gives rise to two male reproductive units, called the **male gametes** (see figs. 245-6). The gynoecium has a chamber at its base, called the **ovary,** which encloses some minute but complex egg-like bodies—the **ovules.** Each ovule bears within its body a female reproductive unit or female gamete, called the **egg-cell** or **ovum** (see fig. 286). The top of the gynoecium which later receives the pollen grains is called the **stigma.**

Fruit, Seed, and Embryo. The seed, although sometimes very small in size, is a complex body formed only in the 'flowering' plants. It develops from the ovule only after certain preliminary processes have taken place in the flower between the stamen and the gynoecium. First, some pollen grains, as the anther bursts, are carried over to the stigma of the gynoecium by wind or by insects, and deposited there; process is called *pollination* (see p. 136). Second, the grains germinate on the stigma, and each forms a sl[illegible] called the **pollen-tube,** which elongates through the tis[illegible]

gynoecium carrying the two male gametes in it and at length enters into an ovule through a minute opening in it (see fig. 301), and there a male gamete fuses with the female gamete, i.e. the egg-cell ; this process is called *fertilization* (see p. 147). Fertilization acts as a powerful stimulus with the result that a series of changes follow in the ovary and sometimes in other parts of the flower: *the egg-cell grows and gives rise to the* **embryo** (*i.e. the baby plant in the seed*), *the ovule to the* **seed,** *and the ovary as a whole to the* **fruit.**. The embryo lies dormant in the seed, and the latter lies embedded in the fruit. The seed and the fruit give adequate protection to the embryo, store up food material for it, and are often well adapted for dispersal. Sooner or later as the seed germinates the embryo grows into a **seedling** which gradually grows into a mature *plant.*

CHAPTER II

THE SEED

The various parts of a seed may be conveniently studied after it has been soaked in water for a day or so varying according to the nature of the seed ; when it is seen to have considerably swelled up and softened in water it may be taken as ready for the study of its parts.

Parts of a Gram Seed (fig. 2)

1. **Seed-coat.** The seed is covered by a brownish coat known as the **seed-coat.** It is made up of two layers or integuments, the outer one being called the **testa** and the inner one the **tegmen.** The testa is brownish in colour and is comparatively thick ; while the tegmen is whitish, thin and mem-

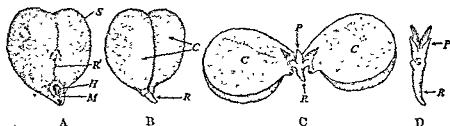


Fig. 2. Gram seed. *A*, entire seed; *B*, embryo (after removal of the seed-coat); *C*, embryo with the cotyledons unfolded; and *D*, axis of embryo. *S*, seed-coat; *R'*, raphe; H, hilum; *M*, micropyle; *C*, cotyledons; *R*, radicle; and *P*, plumule.

branous and is fused with the testa. The seed-coat affords necessary protection to the embryo which lies within. On one

side of the seed, lying above its projected end, a small oval depression may be seen ; this is known as the hilum. The ... nt of the seed to its ... lit may be seen ; this ... cropyle (*mikro*, small ; ... gently pressed, water and minute air-bubbles are seen to escape through it. Above the hilum the stalk is continuous with the seed-coat forming a sort of ridge ; this ridge which is fused with the testa is called the raphe.

2. **Embryo.** The yellowish body, as seen after removing the seed-coat, is the **embryo** or the baby plant. As the seed germinates it gives rise to a seedling which gradually develops in ... small feather). The plumule is surrounded at the apex by a number of minute leaves, and as such it looks more or less like a small feather. As the seed germinates the radicle gives rise to the root and the plumule to the shoot. Cotyledons store up food material.

Gram Seed—
- —Seed coat with testa, hilum, micropyle, raphe and tegmen.
- —Embryo—
  - —Axis with radicle and plumule
  - —Cotyledons—2, fleshy, laden with food.

Parts of a Pea Seed (fig. 3)

1. **Seed-coats.** The seed is somewhat roundish in shape, and is covered by two distinct **seed-coats.** Of the two coats the

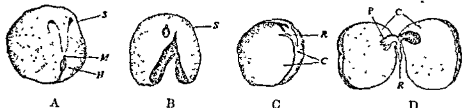


Fig. 3. Pea seed. *A*, entire seed, *B*, seed-coat with hilum and micropyle; *C*, embryo (after removal of the seed-coat); *D*, embryo with the cotyledons unfolded *S*, seed coat—testa (it encloses a thin membranous tegmen); *M*, micropyle; *H*, hilum; *R*, radicle; *C*, cotyledons, *P*, plumule.

outer whitish one is called the **testa** ; it comes off easily when the seed is soaked in water. The testa encloses another coat which is loose, thin, hyaline and membranous ; this inner coat is called the **tegmen.** The seed-coats give necessary protection

to the embryo which lies within. On one side of the testa a narrow, elongated scar representing the point of attachment of the seed to its stalk is distinctly visible: this is the **hilum.** Close to the hilum situated at one end of it there is a minute hole; this is the **micropyle.** On germination of the seed the radicle comes out through it. Continuous with the hilum there is a sort of ridge in the testa; this is the **raphe.**

2. **Embryo.** The whitish fleshy body, as seen after removing the seed-coats, is the **embryo.** It consists of (*a*) *two* fleshy **cotyledons** or seed-leaves and (*b*) a short **axis** to which the cotyledons remain attached. The portion of the axis lying outside the cotyledons, bent inwards and directed towards the micropyle, is (i) the **radicle,** and the other portion of the axis lying in between the two cotyledons is (ii) the **plumule.** The plumule is crowned by some minute young leaves. The radicle gives rise to the root, the plumule to the shoot, and the cotyledons store up food material.

Pea Seed—
- —Seed-coats with testa, hilum, micropyle, raphe and tegmen.
- —*Embryo*—
  - —Axis with radicle and plumule
  - —Cotyledons—2, fleshy, laden with food.

Parts of a Country Bean Seed (fig. 4)

1. **Seed-coat.** The country bean seed (*Dolichos lablab*; B SHIM, H & P. SEM) is more or less oval, and is covered by a

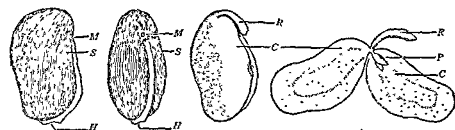


FIG. 4. Country bean seed *M*, micropyle; *S*, seed-coat, *H*, hilum; *R*, radicle; *C*, cotyledons; *P*, plumule

blackish or reddish, hard **seed-coat.** The seed-coat consists of two layers fused together, the outer one being known as the **testa** and the inner one the **tegmen.** At one edge of the seed-coat there is a whitish, elongated ridge; this ridge is called the **raphe.** At the basal portion of the raphe there is a distinct broad scar; this is the **hilum.** At the other end of the raphe away from the hilum there is a minute but distinct hole; this is the **micropyle.** If the soaked seed be gently pressed water and minute air-bubbles are seen to ooze out through it.

2. **Embryo.** On peeling off the seed-coat a distinct, white, fleshy body is seen occupying the whole space within the seed-coat; this is the **embryo.** It consists of (*a*) two fleshy **cotyledons**

and (*b*) an **axis** to which the cotyledons remain attached. The portion of the axis lying externally with its apex directed towards the micropyle is (i) the **radicle**, and the other portion of the axis lying in between the two cotyledons and composed of minute, young leaves is (ii) the **plumule**.

Parts of a Castor Seed (fig. 5)

1. **Seed-coats.** The hard and blackish shell is the outer seed-coat. At one end of the seed-coat there is a white body, an outgrowth formed at the micropyle, called the **caruncle**. Nearly hidden by the caruncle a small scar may be seen on the seed-coat, representing the point of attachment of the seed to its stalk ; this is the **hilum.** On removing the outer hard seed-coat an inner thin and membranous covering may distinctly be seen surrounding the albumen. Of the two seed-coats the outer one is known as the **testa** and the inner one the **tegmen.** *Running down from the hilum a ridge may be seen on the*

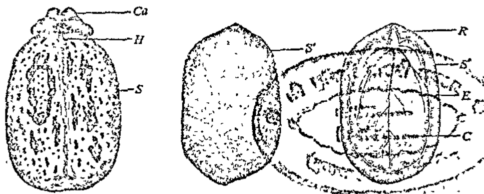


FIG. 5A. Castor seed. *Ca*, caruncle; *H*, hilum; *S*, outer seed-coat; *S'*, inner seed-coat (enclosing the endosperm *E* and the embryo with the radicle *R*, cotyledons *C*, and the minute plumule in between the two cotyledons).

outer seed-coat or testa ; this has been formed by the fusion of the stalk with the testa, and is known as the **raphe.**

2. ***Albumen or Endosperm*** (*endon*, inner or within ; *sperm*, seed). Remove the seed-coats and note, lying inside them, a [illegible] t is the f[illegible] Split open the endosperm and observe that the embryo consists of (*a*) *two* thin, flat and papery **cotyledons** or seed-leaves, more or less distinctly marked by veins, and (*b*) a very short **axis**; the axis consists of (i) a **radicle** which is a little protuberance towards the caruncle, and (ii) an undifferentiated **plumule** which is the blunt inner end of the axis lying in between the two cotyledons. The minute leaves of the plumule become apparent only

the seed begins to germinate. The radicle always gives rise to the root and the plumule to the shoot. Cotyledons lie embedded in the endosperm, and their function is to transport the

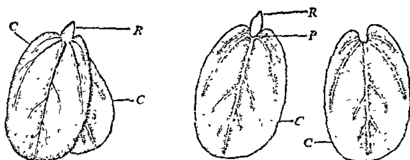


FIG. 5B. Castor seed (*contd*) Embryo— *C*, cotyledon, *R*, radicle; *P*, plumule

food material from the endosperm to the radicle and the plumule, and later, on the germination of the seed they turn green and leafy (see fig. 10).

Castor Seed—
- —Seed-coats with testa, hilum, caruncle, raphe and tegmen.
- —Endosperm laden with food.
- —Embryo—
  - —Axis with radicle and plumule.
  - —Cotyledons—2, thin, leaf-like.

Parts of a Rice Grain (fig. 6)

Rice grain is a small, one-seeded fruit. Each grain remains enclosed in a brownish husk which consists of two parts, one partially enveloping the other; the outer and larger one is called the *flowering glume*, while the inner and smaller one called the *palea*. At the base of the grain are two minute white scales called *empty glumes*. The rice grain and the husk are together known as the paddy grain.

1. **Seed-coat.** On removing the husk a brownish membranous layer is seen adherent to the grain. This layer is made up of the seed-coat and the wall of the fruit fused together.

2. **Endosperm.** This forms the main bulk of the grain and is the food storage tissue of it, being laden with reserve food material, particularly starch. In a longitudinal section of the grain it is seen to be distinctly separated from the embryo by a definite layer known as the *epithelium*.

3. **Embryo.** It is very small and lies in a groove at one end of the endosperm. It consists of only (*a*) *one* shield-shaped cotyledon wh[illegible] [illegible]hort axis which has an [illegible] portion (ii) the radicle. [illegible] e leaves, and the radicle is protected by a cap known as the **root-cap.**

The plumule as a whole (growing point and foliage leaves) is surrounded by a leaf-sheath, called **coleoptile**; similarly the radicle is surrounded by a root-sheath, called **coleorhiza**. On

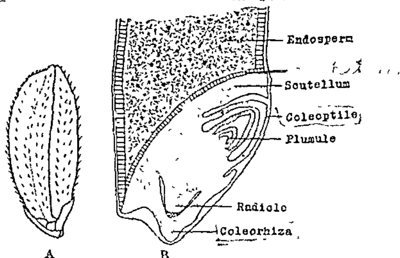


FIG 6 Rice grain. *A*, the grain enclosed in husk; *B*, the grain in longitudinal section (a portion).

the opposite side of the scutellum is a small projection, called **epiblast**—a structure which has been suggested as a suppressed second cotyledon. The surface layer of the scutellum lying in contact with the endosperm is the **epithelium**; its function is to digest and absorb food material stored in the endosperm.

Parts of a Maize Grain (fig. 7)

Like the previous one the maize grain is also a small, one-seeded fruit. The seed is adherent to the wall of the fruit and not separable from it. On one side of the grain a small, opaque, whitish, deltoid area is seen to be distinctly marked out from the rest of the grain. The embryo lies embedded in this area. The grain cut longitudinally through this area shows the following:

1. **Seed-coat.** This is only a thin layer surrounding the whole grain. This layer is made up of the seed-coat and the wall of the fruit fused together.

2. [illegible] ial portions [illegible] he bigger p[illegible] he embryo[illegible] he grain, particularly rich in starch. If the cut surface of the grain is treated with a little iodine solution the whole of the endosperm becomes black indicating the presence of starch, while the embryo takes a yellowish tinge. Thus the two portions become clearly marked.

3 **Embryo.** This consists of (*a*) one shield-shaped cotyle-on, known as the **scutellum,** as in the rice grain, and (*b*) an xis. The upper portion of the axis with minute leaves arching ver it is (i) the **plumule,** and the lower portion provided with

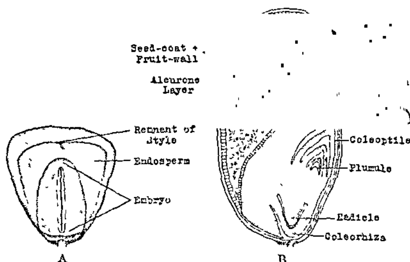


FIG. 7 Maize grain *A*, the entire grain; *B*, the grain in longitudinal section

he **root-cap** (ii) the **radicle.** The plumule is surrounded by leaf-sheath or **coleoptile,** and the radicle is surrounded by root-sheath or **coleorhiza.** Coleoptile and coleorhiza are rotective sheaths of the plumule and the radicle respectively, nd are characteristic of the grass family and the palm family. The surface layer of the scutellum lying in contact with the ndosperm is the *epithelium*; its function is to digest and bsorb food material stored in the endosperm.

Note. In cereals (e g. rice, wheat, maize, barley and oat), nillets and other plants of the grass family the cotyledon is nown as the **scutellum.** It supplies the growing embryo with ood material absorbed from the endosperm with the help of the pithelium.

Maize Grain—
- —Seed-coat with the fruit-wall fused with it.
- —Endosperm laden with food material.
- —Embryo—
  - —Axis with radicle & coleorhiza and plumule & coleoptile.
  - —Cotyledon (scutellum)—1, shield-shaped

Dicotyledons and Monocotyledons

'Flowering' plants have been divided into two big classes: dicotyledons (*di*, two) and monocotyledons (*monos*, single). The division is based on the following characters: (1) in dicotyledons the embryo of the seed bears *two cotyledons*, while

in monocotyledons it bears only *one*; (2) in the dicotyledonous embryo the plumule is *terminal* and the cotyledons *lateral*, while in the monocotyledonous embryo the reverse is the case; (3) in dicotyledons the primary root persists and gives rise to the *tap root*, while in monocotyledons the primary root soon perishes and is replaced by a cluster of *fibrous roots*; (4) as a rule the venation of the leaf is *reticulate* (net-like) in dicotyledons, while it is *parallel* in monocotyledons (with but few exceptions in both the cases); and (5) dicotyledonous flower has commonly a *pentamerous symmetry*, while monocotyledonous flower a *trimerous symmetry*.

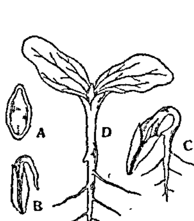
Dicotyledons far outnumber monocotyledons, being represented by 159,000 and 40,000 species respectively. Some of the common dicotyledons are: gram, pea, bean, tamarind, gourd, cotton, orange, sunflower, guava, jack, mango, castor, poppy, etc., and some of the common monocotyledons are: rice, wheat, maize, grasses, lilies, palms, aroids, onion, orchids. etc.

Albuminous and Exalbuminous Seeds

1. Seeds that possess a special food storage tissue, called the albumen or endosperm, are said to be **albuminous** or endospermic, and those that possess no such special tissue for food storage are said to be **exalbuminous** or non-endospermic. In dicotyledonous seeds the endosperm surrounds the embryo which lies within; while in monocotyledonous seeds the endosperm may lie on one side, as in cereals, or the embryo may lie embedded in the [illegible] required for the use of the embryo when germination of the seed takes place.[1]

2. In all seeds the food accumulates in the endosperm tissue at an early stage of seed-development. But in albuminous seeds the endosperm continues to store food. Because of this, coupled with the formation of new cells, the endosperm grows and enlarges rapidly. Ultimately in the mature seed it acts as the food storage tissue. In such seeds the single cotyledon (in monocotyledons) or the two cotyledons (in dicotyledons) are [illegible] and fleshy. Common examples are as follows:

[1] For 'food stored in the seed' see end of Chapter VIII, Part III.



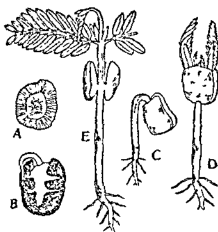
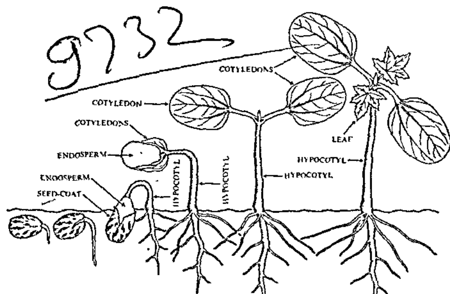


FIG. 8 FIG. 9
Epigeal Germination Fig. 8. Gourd seed. Fig. 9. Tamarind seed.



Epigeal Germination. FIG. 10. Castor seed.

2. Hypogeal Germ[illegible] as gram, p[illegible] cotyledons a[illegible] In such cas[illegible] immediately [illegible] plumule up[illegible] gradually d[illegible] called hypoge[illegible]

Hypogeal Germination of Monocotyledonous Seeds (figs. 13-4). Monocotyledonous seeds are mostly all[illegible] germination the co[illegible]

the soil; germination is, therefore, hypogeal (except in the case of onion, see fig. 17). In the germination of monocotyle-

Fig. 11

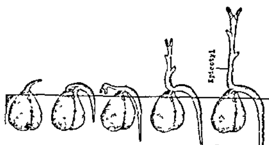
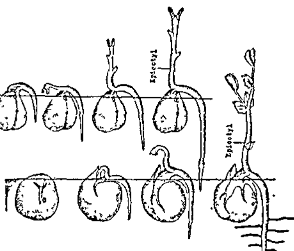
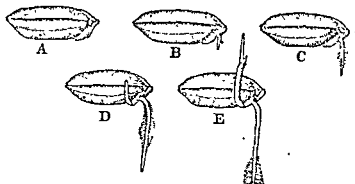



Fig 12

Hypogeal Germination Fig. 11. Gram seed Fig. 12 Pea seed.

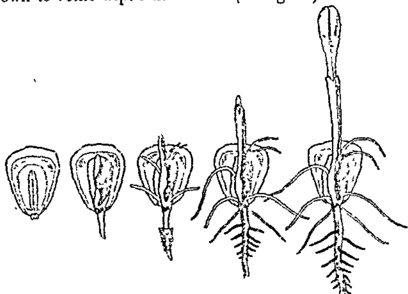
donous seeds like paddy and maize, the *cotyledon* or *scutellum* absorbs the food material stored up in the endosperm. On germination the radicle makes its way through the lower



Hypogeal Germination. Fig. 13. Paddy.

short, collar-like end of the sheath called the root-sheath or **coleorhiza**; while the *plumule breaks through the upper* distinct, cylindrical portion of the sheath, called the plumule-sheath or **coleoptile** (figs. 13-4). The radicle grows downwards and at first it develops into the primary root. In most cases the primary root soon perishes and a cluster of fibrous roots appears from the base. The plumule grows upwards. The first leaf soon emerges out of the plumule-sheath and others follow in succession. In the *germination of many palms, e.g.* date-palm and palmyra-palm (but not coconut-palm) a part of the cotyledon extends into a sheath, long or short, which

encloses the axis of embryo a little behind the tip and carries it down to some depth in the soil (see fig. 18).



Hypogeal Germination. FIG. 14 Maize grain.

Special Type of G[illegible] [illegible]
salt-lakes a [illegible]
their seeds, [illegible]
inside the [illegible] still attached to the parent tree and nourished by it. The radicle elongates, swells in the lower part and gets stouter. Ultimately the seedling separates from the parent plant due to its increasing weight, and falling vertically becomes embedded in the soil mud below. The radicle presses into the soil, and quickly lateral roots are formed for proper anchorage. Examples are seen in *Rhizophora*, *Sonneratia* (B. KEORA), *Heritiera* (B. SUNDRI), etc.

Conditions necessary for Germination. Dry seeds retain their viability for many months and even years depending on their nature, provided, of course, that the embryo is not damaged by insects or fungi. Then the following external conditions are necessary for their germination: (1) **water or moisture**, (2) **moderate temperature**, and (3) **air or oxygen.**

1. **Moisture.** For germination of a seed protoplasm must be saturated with water. In air-dried seeds water content is usually 10-15%. No vital activity is possible at this low water content. Water is thus necessary to bring about the vital activity of the dormant embryo; to dissolve various salts and organic substances stored in the cotyledons or in the endosperm; to facilitate necessary chemical changes; and to help the embryo to come out easily by softening the seed-coat.

2. **Temperature.** A suitable temperature is necessary for the germination of a seed Protoplasm functions normally within a certain range of temperature. Within limits which vary according to the nature of the seed, the higher the temperature the more rapid is the germination

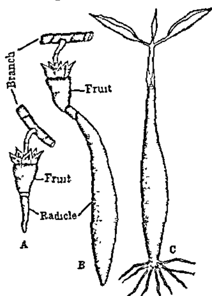


FIG 15. Viviparous germination. A-B, stages in germination; C, seedling.

3. **Air.** Oxygen, *one of* the constituents of air, is necessary for respiration of a germinating seed By this process a considerable amount of energy stored in the food material is *liberated* and *made use of by the protoplasm. Respiration in* the germinating seed is very vigorous as the active protoplasm requires a constant supply of oxygen, and hence the seed sown deeply in the soil shows very little or no sign of germination.

It may be noted in this connexion that **light** *is not an* essential condition of germination. In fact seeds germinate more quickly in the dark. Some seeds—tomato, for example—will not germinate unless they are kept in the dark. For subsequent growth, however, light is indispensable. Seedlings grown continually in the dark, elongate rapidly but become frail, *develop no chlorophyll and bear only pale, undeveloped* leaves. In this condition seedlings are said to be *etiolated*.

Three Bean Experiment (fig. 16). That all the conditions mentioned above are essential for germination can be shown by a simple experiment, known as the **three bean experiment.** Three air dry seeds are attached to a piece of wood, one at each *end and one in the middle.* This is then placed in a beaker, and water is poured into it until the middle seed is half immersed in it. The beaker is then left in a warm place for a few days. From time to time water is added to maintain the original level. It is seen that the middle bean germinates normally because it has sufficient moisture, oxygen and heat. The bottom bean has *sufficient moisture and heat*, but not oxygen. It may be seen only to put out the radicle, but further development is checked for want of oxygen. The *top* bean having only sufficient oxygen and heat, but not moisture, does not show any sign of germination.


FIG. 16. Three bean experiment.

This experiment evidently shows that moisture and oxygen are indispensable for germination; the effect of temperature

is only indirectly proved. It can, however, be directly proved in the following way. Other conditions remaining the same, if the temperature be considerably lowered or increased by placing the beaker with seeds in a freezing mixture or in a bath with high constant temperature it will be seen that none of the beans will germinate. Thus suitable temperature is also an essential condition for germination.

Structure and Germination of Onion Seed (fig. 17)

Structure. The seed is small, black, roughly semi-circular in shape, flattened on one side and grooved at the narrow end. Its outer black covering is (a) the **seed-coat or testa.** Cut the seed lengthwise and observe (b) the **endosperm** which is the thin whitish mass within the seed-coat, and

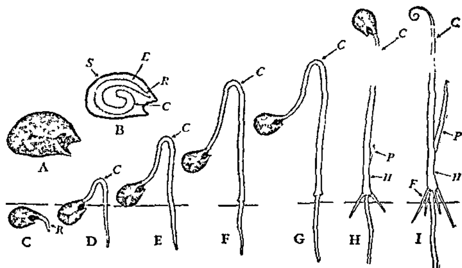


Fig. 17. Onion seed. *A*, an entire seed; *B*, the seed in longitudinal section; *C—I*, stages in germination; *S*, seed-coat; *E*, endosperm; *R*, radicle; *C*, cotyledon; *P*, plumule; *H*, hypocotyl; and *F*, fibrous roots.

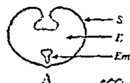
(c) the embryo which is the slender, elongated, colourless, curved body lying embedded in the endosperm. The embryo consists of (i) a **single cotyledon** and (ii) a **radicle.** The bigger portion of the curved body looped at the end is the cotyledon, and the narrow end of it directed towards the pointed end of the seed is the radicle The plumule which is very minute and undifferentiated lies hidden laterally in the region of the very short hypocotyl, and is distinguishable clearly only on the germination of the seed.

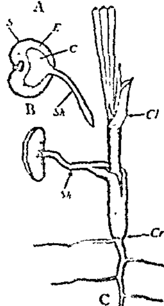
Germination. As germination takes place the radicle comes out through the pointed end of the seed and grows downward [C]. The cotyledon elongates, emerges out of the seed except its looped end and forms a distinct arch or loop [D] It turns green in colour and further elongates as a leaf-sheath lifting the seed from the soil [E]. The germination is **epigeal.** The end of " and functions as an absorbing organ c d supplying the same to the growing and the cotyledon turns deep green i [F-G]. The cotyledon grows further and almost straightens out bearing the seed on the top [H] A slight swelling appears at the base of the hypocotyl and a few fibrous roots push out from this region. A little higher up the plumule soon pierces the leaf-sheath and grows upward as a slender body. It turns green and forms

the second leaf of the seedling. The coiled end of the cotyledon withers and the seed-coat drops now or a little later [I]. By this time the endosperm has already become exhausted.

Structure and Germination of Date-palm Seed (fig. 18)

The black stony covering of the seed is the **seed-coat**. Note that it remains adherent to the seed; there is a deep groove along one side of it. When the seed is cut across in the middle a whitish mass will be seen filling up the cavity, this whitish mass is the **kernel** or **endosperm**. Like the seed-coat, it is also hard and woody. Its cell-walls are very thick, due to a heavy deposit of hemicellulose (or reserve cellulose). The **embryo** lies embedded in the endosperm near the periphery away from the groove.





When germination begins the single **cotyledon** enlarges. It secretes a digestive agent which acts upon the reserve cellulose and renders it soluble (the reserve cellulose is converted into sugar). The cotyledon absorbs the sugar and grows at the expense of the endosperm. A portion of the cotyledon breaks through the seed-coat in the form of a **sheath** enclosing the **axis of the embryo** inside it. This **sheath** of the cotyledon elongates and carries down with it the axis of the embryo. After it has gone into the soil the **radicle** of the axis comes out piercing the root-sheath or **coleorhiza**, grows downwards and produces the root. Eventually the plumule bursts the plumule-sheath or **coleoptile** and grows upwards into the air, forming the shoot.

Structure and Germination of Coco-

light and then function like ordinary leaves, i.e. they manufacture food in the presence of sunlight.

4. The cotyledons act as protective organs. The plumule lies in between the two cotyledons, and at the seed stage and during the early germination period they give adequate protection to it (the plumule).

5. In monocotyledonous seeds at the time of germination the cotyledon absorbs food from the endosperm, and at length extends as a sort of sheath, long or short, pushing the radicle and the plumule out of the seed. In many palms, as in palmyra-palm and date-palm, a fairly long sheath is produced (see fig. 18).

CHAPTER III

THE ROOT

The **root** is the descending portion of the axis of the plant and develops from the radicle of the embryo. The direct prolongation of the radicle forms what is known as the **primary root.** If it persists and continues to grow it is called **the tap root.** The tap root is normally formed in dicotyledons. It produces lateral branches which are known as the *secondary roots*, and these in turn produce the *tertiary roots*, and so on. All these lateral roots are produced in *acropetal* succession, i.e. the older and longer roots are away from the tip, and the



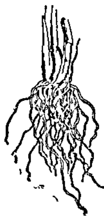






Fig. 20 Fig. 21 Fig. 22 Fig. 23

Fig 20 Tap and lateral roots in a dicotyledon. Fig. 21. Fibrous roots in a monocotyledon Fig. 22. Multiple root-cap in screwpine. Fig. 23. Root-pockets in duckweed (see p. 23).

younger and shorter ones are towards it. The tap root system may be regarded as characteristic of dicotyledons.

In monocotyledons the radicle also gives rise to the primary root, but this does not develop any further or soon perishes and is replaced by a cluster of thin roots developed from the base of the stem. These are known as the fibrous roots. The[illegible]
or [illegible]
In [illegible]
for a shorter or longer period. The fibrous root system may be regarded as characteristic of monocotyledons.

Regions of the Root (fig. 24). The following regions may be distinguished in a root from the apex upwards. There is of course no line of demarcation between one region and the other. As a matter of fact one merges into the other.

1. **Root-cap.** Each root is covered over at the apex by a sort of a cap or thimble known as the root-cap which protects the tender apex of the root as it makes its way through the soil. Due to the impact of the hard soil particles as the outer part of the root-cap wears away newer cells formed by the underlying growing tissue are added to it. The root-cap is in fact the protective region of the root. It is, however, usually absent in the aquatic plant.

2. **Region of cell-division.** This is the growing apex of the root lying within and a little beyond the root-cap and extends to a length of one to a few millimetres The cells of this region are very small and thin-walled, and contain a dense mass of protoplasm. The characteristic feature of this region is that the cells are undergoing repeated divisions, and hence this region is otherwise called the **meristematic region** (*meristos*, to divide). Some of the newly formed cells contribute to the formation of the root-cap and others to the next upper region.

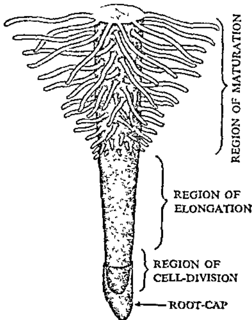


FIG. 24. Regions of the root.

3. **Region of Elongation.** It lies above the meristematic region and extends to a length of a few millimetres (1 to

5 mm. or a little more). The cells of this region undergo rapid elongation and enlargement, and are responsible for growth in length of the root.

4. **Region of Maturation.** This region lies above the region of elongation and extends upwards. Externally, often extending to a length of a few millimetres and sometimes a few centimetres, this region produces a cluster of very fine and delicate thread-like structures known as the **root-hairs.** These hairs are essentially meant to absorb water and mineral salts from the soil. Internally, the cells of this region are seen to undergo maturation and differentiation into various kinds of primary tissues. Higher up it gradually merges into the region of secondary tissues. Above the root-hair region lateral roots are produced in *acropetal* succession.

Characteristics of the Root. There are certain distinctive characters of the root by which it can be distinguished from the stem. These are as follows:—

1. The root is the descending portion of the axis of the plant, and grows away from light; while the stem is the ascending portion of the axis and it turns towards light. It is furthe
as the
when
green

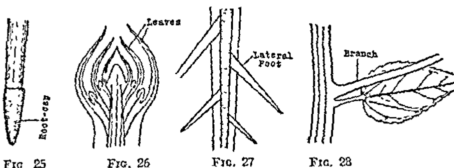


Fig 25 Fig. 26 Fig. 27 Fig. 28

Fig. 25. Root-tip Fig 26 Stem apex Fig 27. Lateral root (endogenous; see also fig. 447). Fig. 28 Branch (exogenous)

(B. GULANCHA ; H. GURCHA ; P. GALO) and water chestnut (*Trapa* ; B. PANI-PHAL ; H. & P. SINGARHA). In water chestnut submerged roots are green in colour.

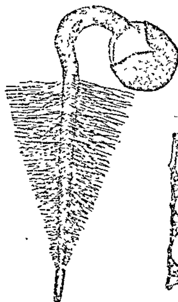
2. The ... buds; while the normal funct... vegetative and floral buds f... uction. There are, however, cases where the roots are seen to bear vegetative buds (but not floral buds) for vegetative propagation. These

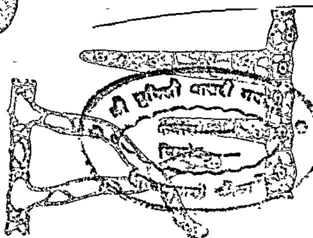
buds grow into new plants, as in wood-apple (*Aegle*), *Trichosanthes* (B. PATAL ; H. PARWAL), Indian redwood (*Dalbergia* ; B. SISSOO ; H. & P. SHISHAM), sweet potato, lemon, citron, rose and ipecacuanha. Such plants are sometimes propagated by root-cuttings, e.g. ipecacuanha.

3. The root ends in and is protected by a cap- or thimble-like structure, known as the **root-cap** (fig. 25) ; while the stem ends in a bud—the terminal bud, which consists of the growing apex of the stem surrounded by a number of young leaves (fig. 26). A distinct, multiple root-cap is seen in the aerial root of screwpine (B. KETUCKY ; H. & P. KEORA—fig. 22).

In water plants like duckweed (*Lemna*), water lettuce (*Pistia*), water hyacinth, etc , a loose sheath which comes off easily is distinctly seen at the apex of each root. This is an anomalous root-cap, called the **root-pocket** (fig. 23).

4. The root bears **unicellular hairs** (fig. 30) ; while the stem or the shoot bears mostly **multicellular hairs** (fig. 31), although unicellular shoot-hairs are not uncommon. Root-hairs occur in





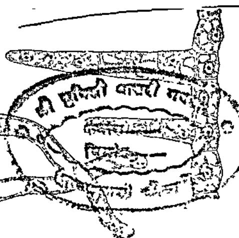


FIG. 29 FIG. 30 FIG. 31

Fig. 29. Root-hairs in mustard seedling. Fig. 30. Two root-hairs (magnified)—unicellular. Fig 31. Two shoot-hairs (magnified)—multicellular.

a cluster in the tender part of the root a little behind the apex. In the early seedling stage, however, root-hairs develop all over the root. Later on as the root grows, older root-hairs die off and newer ones are formed towards the apex. Shoot-hairs, on the other hand, are of various kinds (see p. 37) and they remain scattered all over the surface of the shoot. Root-hairs have very thin walls made of cellulose ; while shoot-hairs are somewhat

thickened and cutinized, at least at the base. Root-hairs are short-lived, usually persisting for a few days or weeks; while shoot-hairs last for a much longer time. Root-hairs absorb water and mineral salts from the soil, and shoot-hairs prevent evaporation of water from the surface of the plant body and afford protection.

5. Lateral roots always develop from an inner layer (fig. 27); so they are said to be **endogenous** (*endo*, inner; *genes*, to form). Branches, on the other hand, develop from a few outer layers (fig. 28); so they are said to be **exogenous** (*exo*, outer)

6. **Nodes** and **internodes** are always present in the stem, although they may not often be quite distinct; but in the root these are absent.

KINDS OF ROOTS

Tap Root System. The primary root and its branches form the tap root system of the plant. The primary or tap root normally grows vertically downwards to a shorter or longer depth, while the branched roots (secondary, tertiary, etc.) grow obliquely downwards, or in many cases spread horizontally outwards. The primary root may be sparingly or profusely branched according to the need of the plant. The tap root *system is normally meant to absorb water and mineral salts* from the soil, to conduct the same upwards to the stem and to give proper anchorage to the plant, but in order to carry on some specialized functions it becomes modified into distinct shapes (see p. 27).

Adventitious Root System. Roots that grow from any part of the plant body other than the radicle are called the **adventitious roots.** They may develop from the base of the stem replacing the primary root or in addition to it, or from any [illegible] of the stem or the branch or in special cases [illegible] various kinds and [illegible] ions these roots go down into the soil and behave like ordinary roots, while for specialized functions which many such roots carry on they assume different shapes to meet different needs, and may be subterranean or aerial. Adventitious roots carrying on normal functions may be of the following types:

1. **Fibrous Roots** (fig. 21). Fibrous roots of monocotyledons are all adventitious roots. They may be given off in clusters from the base of the stem, as in onion, tuberose, etc., or from the nodes and sometimes internodes of branches creep-

ing on the ground, as in many grasses, or from the lower nodes of the stem, as in maize, sugarcane, bamboo, etc

2. **Foliar Roots** (fig. 32). Foliar roots are those that directly come out of the leaf, mainly from the petiole or the

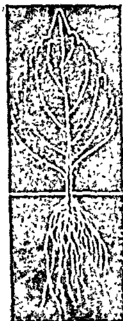


Fig. 32. Foliar (adventitious) roots in *Pogostemon*.

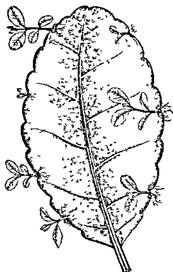


Fig. 33. Adventitious roots in *Coleus*.

vein. Such roots may sometimes arise spontaneously, or more commonly as a result of injury (e.g., when incised), or they may be induced to grow by the application of certain chemicals, called *hormones*, which are growth promoting substances. Th[illegible] with a synthetic hormone, e.g. [illegible] produce a cluster of roots fro[illegible] not common in nature but can be induced to grow by the above treatment.[1]

3. **Adventitious roots** are also given off by many plants from their nodes and sometimes from the internodes as they creep on the ground, as in Indian pennywort (see fig. [illegible]), wood-sorrel (see fig. [illegible]), etc. Such roots are also produced in many

cases from branch-cuttings when these are put into the soil, as in rose, sugarcane, China rose, marigold, tapioca, etc. or kept partially immersed in water in a bottle, as in garden croton, *Coleus* (fig. 33), etc. Adventitious roots also grow from foliar buds developing on leaves. Thus the leaf of sprout leaf



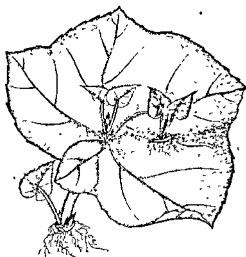


FIG 34 FIG. 35

Fig. 34. Foliar buds and adventitious roots of sprout leaf plant (*Bryophyllum*). Fig 35 The same of elephant-ear plant (*Begonia*).

plant (*Bryophyllum pinnatum*; B. PATHUR-KUCHI; H. ZAKHM-I-HAYAT) produces a number of buds on its margin (fig. 34). These buds are provided with a tuft of slender adventitious roots which go into the soil and fix the buds or the leaf as a whole to the soil. The leaf of *Kalanchoe* (B. HIMSAGAR; H. HAIZA—see fig. 509) similarly develops adventitious buds and roots on the margins near the apex. In the elephant-ear plant (*Begonia*) also similar buds and roots are produced all over the surface of the leaf from the veins and the petiole (fig. 35).

MODIFIED ROOTS

Specialized functions of varied nature are carried on by the modified roots which adapt themselves according to the particular need of the plant. For these purposes both the tap root and the adventitious roots may undergo modifications. Thus it is seen that for *storage of food* roots (both tap and adventitious) of some plants become thick, fleshy and often succulent.

Other *specialized* functions are met by certain types of adventitious roots which become modified accordingly to meet each need.

A. Tap Root Modified (for storage of food)

1. **Fusiform Root** (fig. 36). When the root (hypocotyl) is swollen in the middle and gradually tapering towards the apex and the base, being more or less spindle-shaped in appearance, it is said to be fusiform, e.g. radish. In radish it is really the hypocotyl and the base of the stem that swell; only the tapering end is the root proper.

2. **Napiform Root** (fig. 37). When the root is considerably swollen at the upper part (usually the hypocotyl), becoming almost spherical, and sharply tapering at the lower part, it is said to be napiform, e.g. turnip and beet. In turnip it is the hypocotyl that swells and becomes spherical; while in beet the hypocotyl and the root together become swollen.

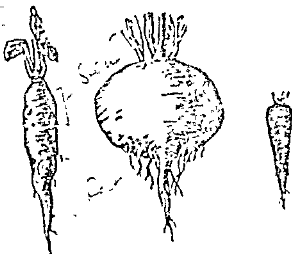


FIG. 36 FIG. 37 FIG. 38
Modified Roots Fig. 36. Fusiform root of radish. Fig. 37. Napiform root of turnip. Fig. 38. Conical root of carrot.

3. **Conical Root** (fig. 38). When the root is broad at the base and it gradually tapers towards the apex like a cone, it is said to be conical, e.g. carrot. In carrot it is the root proper that swells.

4. **Tuberous or Tubercular Root.** When the root is thick and fleshy but does not maintain any particular shape, it is said to be tuberous or tubercular, as in four o'clock plant (*Mirabilis*; B. KRISHNAKOLI; H. GUL-ABBAS; P. GUL-E-ABBASI).

B. Branched Root Modified (for respiration)

5. **Pneumatophores.** Many plants growing in marshy

places and salt lakes, occasionally inundated by tides, as in the Sundarbans, develop a special kind of roots, called respiratory roots or **pneumatophores** (figs. 39-40), for the purpose of respiration. Such roots grow from the underground roots of the plant but rise vertically upwards and come out of the water like so many conical spikes. They often occur in large numbers around the tree trunk. Each such root is provided towards the upper

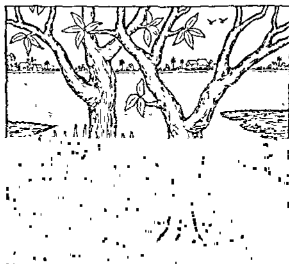


FIG 39

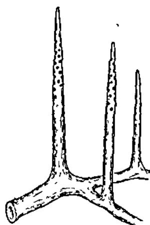


FIG. 40

Pneumatophores Fig. 39 Two plants with pneumatophores. Fig. 40. Pneumatophores growing vertically upwards from an underground root.

end with numerous pores or respiratory spaces through which air is taken in for respiration. Examples are seen in *Rhizophora*, *Heritiera* (B. SUNDRI), etc.

C. Adventitious Roots Modified

(*a*) *For Storage of Food*

1. **Tuberous or Tubercular Root** (fig. 41). This is a swollen root without any definite shape, as in sweet potato (*Batatas*; B. MITHA-ALOO; H. SHAKARKAND). Tuberous roots, whether tap or adventitious, are produced singly and not in clusters.

2. **Fasciculated Roots** (fig. 42). When several tubercular roots occur in a cluster or fascicle at the base of the stem, they are said to be fasciculated, as in *Dahlia*, *Ruellia* and *Asparagus* (B. SATAMULI; H. & P. SATAWAR).

3. **Nodulose Root** (fig. 43). When the slender root becomes suddenly swollen near the apex, it is said to be nodulose,

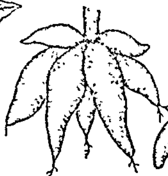
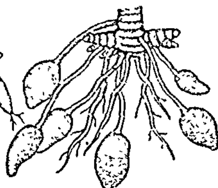




FIG. 41 FIG. 42 FIG. 43

Adventitious Roots. Fig. 41. Tuberous roots of sweet potato Fig. 42. Fasciculated roots of *Dahlia*. FIG. 43. Nodulose roots of mango ginger.

as in mango ginger (*Curcuma amada* ; B. AMADA ; H. AM-HALDI) and arrowroot (*Maranta*).

4. **Moniliform or Beaded Root** (fig. 44). When there are some swellings in the root at frequent intervals, it is said to be moniliform or beaded, as in Indian spinach (*Basella;* B. PUI ; H. POI), *Momordica* (B. KAKROL; H. CHATTHAI), *Vitis trifolia* (B. AMAL-LATA ; H. AMALBEL) and some grasses.

5. **Annulated Root** (fig. 45). When the root has a series of ring-like swellings on its body, it is said to be annulated, as in ipecacuanha (a medicinal plant cultivated in the Darjeeling district along with *Cinchona*).

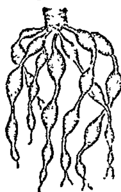
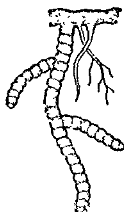



FIG 44 FIG. 45

Adventitious Roots (*contd.*). Fig. 44. Moniliform roots of *Momordica*. Fig. 45 Annulated roots of ipecacuanha

(*b*) *For Mechanical Support*

6. **Prop or Stilt Roots** (figs. 46-7) In plants like banyan, India-rubber plant, screwpine, *Rhizophora*, etc., a number of roots are produced from the main stem and often from the

branches. These roots grow vertically or obliquely downwards

Fig. 46 Fig. 47

Adventitious Roots (*contd.*) Fig. 46 Prop or stilt roots of banyan. Fig. 47. The same of screwpine.

and penetrate into the soil. Gradually they get stouter and act as pillars supporting the main stem and the branches or the plant

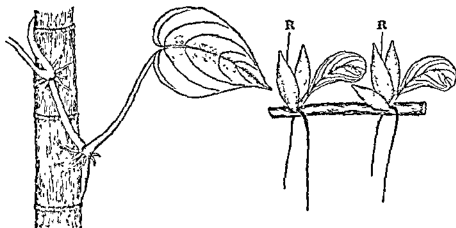


Fig. 48 Fig. 49

Adventitious Roots (*contd.*). Fig. 48. Climbing roots of betel. Fig. 49. Respiratory roots (*R*) of *Jussiaea*

as a whole. Such roots are known as **prop or stilt roots.** The big banyan tree of the Indian Botanic Garden near Calcutta has produced near about 900 such roots from its branches

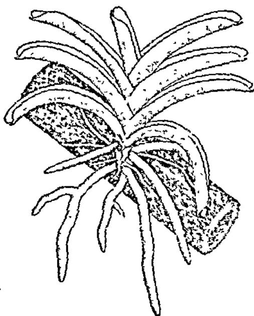
Its age is estimated to be about 190 years, and the circumference of the crown over 1,200 ft.

7. **Climbing Roots** (fig. 48). Climbing plants like betel (*Piper betle*), long pepper (*P. longum*), black pepper (*P. nigrum*), *Pothos*, etc., produce roots from their nodes and often from the internodes, by means of which such plants attach themselves to their support and climb it. To ensure a foothold such roots secrete a kind of sticky juice which quickly dries up in the air, as seen in ivy (*Hedera helix*) and Indian ivy (*Ficus pumila*; see fig. 53). Often they form at their apex a disc-like structure or a sort of claw for firmer foothold. Such roots are also called **clinging roots.**

(*c*) *For Vital Functions*

8. **Sucking Roots or Haustoria** (see figs. 65-6). Parasites develop a kind of roots which penetrate into the tissue of the host plant and suck it. Such roots are known as the sucking roots or haustoria (sin. haustorium). Parasites, particularly non-green ones, have to live by absorbing the food from the host plant with the help of their sucking roots. Common examples are dodder (*Cuscuta*; B. SWARNALATA; H. AKASHBEL; P. AMARBELL—see fig. 65), *Cassytha* (B. AKASH-BEL; H. AMARBELI), broomrape (*Orobanche*; B. BANIA-BAU; H. SARSON-BANDA—see fig. 67), mistletoe (*Viscum*; B. BANDA; H. BHANGRA—see fig. 69) and *Loranthus* (B. MANDA; H. & P. BANDA).

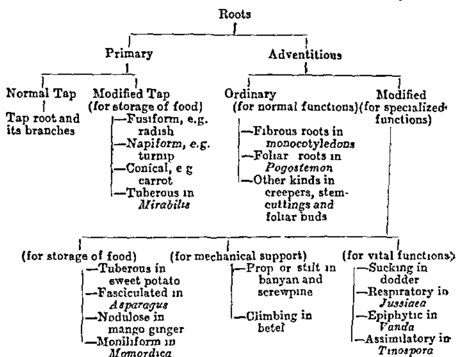
9. **Respiratory Roots** (fig. 49). In *Jussiaea* (B. KESSRA), an aquatic plant, the floating branches develop a kind of adventitious roots which are soft, light, spongy and colourless. They usually develop above the level of water and serve to store up air. Thus they facilitate respiration.


FIG. 50. Epiphytic roots of *Vanda* (an orchid).

10. **Epiphytic Roots** (fig. 50). There are certain plants, commonly the orchids, which grow perched on branches of trees. Such plants are known as **epiphytes** (*epi*, upon; *phyta*, plants). They never suck the supporting plant as do the para-

sites. So instead of sucking roots they develop a special kind aerial roots which hang freely in the air. Each hanging root is surrounded by a spongy tissue, called **velamen** (see fig. 71). With the help of this velamen the hanging root absorbs moisture from the surrounding air. *Vanda* (B. RASNA), an epiphytic orchid, is a common example.

11. **Assimilatory Roots.** Branches of *Tinospora* (B. GULANCHA ; H. GURCHA ; P. GALO) climbing on neighbouring trees produce long, slender, hanging roots which develop chlorophyll and turn green in colour. These green roots are the assimilatory roots. They carry on carbon-assimilation, i.e. they absorb carbon dioxide from the air and manufacture carbohydrate food. The hanging roots of epiphytic orchids also often turn green in colour and act as assimilatory roots.



Functions and Adaptations of the Root. The root performs manifold functions—*mechanical* such as **fixation,** and *physiological* such as **absorption, conduction** and **storage.** These are the normal functions of the root. Roots also carry on specialized functions and they adapt themselves accordingly. All these functions and adaptations have been discussed in detail in connexion with the modified roots (see pp. 26-32).

1. **Fixation.** The mechanical function that the root performs is the fixation of the plant to the soil. The main root

goes deep into the soil and the lateral roots spread out in different directions; so the root system as a whole firmly anchors the plant. In monocotyledons this anchorage is afforded by the fibrous roots.

2. **Absorption.** The most important physiological function is the absorption of water and raw food material from the soil. This is done with the help of root-hairs which develop in a cluster at a little distance behind the root-cap. These root-hairs adhere to the soil particles and absorb water and soluble salts from them.

3. **Conduction.** The root is also concerned in the conduction of water and mineral salts, sending them upwards into the stem and ultimately into the leaf.

4. **Storage.** There is a certain amount of food stored up in the root, particularly in its mature region. As the root grows this stored food is utilized.

It may be summarized that anchorage, conduction and storage are carried on normally by the older portions of the root system, and absorption by the root-hairs and tender portions.

CHAPTER IV

THE STEM

Characteristics of the Stem. The stem is the ascending portion of the axis of the plant, developing directly from the plumule, and bears leaves, branches and flowers. When young, it is normally green in colour. The growing apex is covered over and protected by a number of tiny leaves which arch over it (see fig. 51). The stem often bears multicellular hairs of different kinds
with nodes and
cases. Leaves an
When the stem
p. 35) it continuc
it ends in a floral bud the growth ceases.

Some Descriptive Terms. The stem is usually **cylindrical** in shape, but in the sedges it becomes **triangular**, and in sacred basil (*Ocimum*; B. & H. TULSI) and some other plants it is **quadrangular.** A variety of forms is seen in cacti. In some spurges (*Euphorbia*) the stem becomes fleshy and succulent. It may be ribbed with alternate ridges and furrows, as in gourd, or distinctly jointed, as in sugarcane. When the stem is hollow

it is said to be **fistular,** as in coriander. It may also undergo modification into some special form.

FORMS OF STEMS

There is a variety of stem structures adapted to carry on diverse functions. They may be aerial or underground. Aerial stems may be erect, rigid and strong, holding themselves in an upright position; while there are some too weak to support themselves in such a position. They either trail along the ground or climb neighbouring plants or objects. Some stems remain permanently underground and from there periodically give off aerial shoot under favourable conditions; such stems are meant for food storage and perennation (see pp. 47-51).

I. Erect or Strong Stems. The unbranched, erect, cylindrical and stout stem, marked with scars of fallen leaves, is called **caudex,** as in palms. The jointed stem with solid nodes and hollow inter-nodes is called **culm,** as in bamboo. Some herbaceous plants, particularly monocotyledons, have no aerial stem. The underground stem in them remaining suppressed gives rise to a cluster of leaves which thus appear as if coming out of the root. At the time of flowering, however, this underground stem produces through the cluster of leaves an erect unbranched aerial shoot bearing either a single flower or a cluster of flowers; such a flowering shoot is called **scape,** and the plant is said to be *acaulescent* (*a*, without; *caulis*, stem), or apparently stemless. The scape dries up as soon as the flowering season is over. Common examples are tuberose (B. RAJANIGANDHA; H. & P. GUL-SHABO), onion, aroids, lotus, water-lily, etc. The scape is leafless or almost so; in tuberose the green leafy structures are bracts.

When the main stem continues to grow indefinitely giving off branches from its sides in *acropetal* succession so that the general form becomes pyramidal, it is technically said to be **excurrent,** as in mast tree (*Polyalthia*; B. DEBDARU; H. DEVADARU or ASHOK), beef-wood tree (*Casuarina*; B. & H. JHAU), etc., and when the growth of the main axis is checked and soon exceeded by the lateral branches which spread in all directions so that the general form becomes dome-shaped, it is said to be **deliquescent,** as in banyan.

II. Weak Stems. A weak stem trailing on the ground without rooting at the nodes is commonly known as (1) **trailing;** a trailing stem lying prostrate on the ground is said to be **prostrate** or **procumbent,** e.g. purslane (*Portulaca*; B. NUNIASAK: H. KULFA-SAG) and *Evolvulus* (H. SHYAMAKRANTA). When the stem after trailing on the ground for some distance tends to rise at the apex, it is known as **decumbent,** e.g. *Tridax* (see fig. 777). When the stem is much branched and the branches

spread out on the ground in all directions, it is said to be **diffuse,** as in hogweed (*Boerhaavia*; B. PUNARNAVA; H. THIKRI or SANT). A weak stem creeping on the ground and rooting at the nodes is said to be (2) **creeping**; a creeping stem may be a runner, stolon, offset or sucker according to its varied nature (see pp. 51-3). When the weak stem attaches itself to any neighbouring object by means of some special devices and climbs it, the stem is said to be (3) **climbing,** e.g. pea, passion-flower, gourd, vine, etc. (see pp. 38-42).

Nodes and internodes. The place on the stem or branch where one or more leaves arise is known as the node, and the space between two successive nodes is called the internode. Sometimes nodes and internodes are very conspicuous, as in bamboos and grasses; in others they are not always clearly marked.

THE BUD

A bud (fig. 51) is a condensed or an undeveloped shoot in which the internodes have not yet elongated; the young rudimentary leaves, which are in the course of development, are closely crowded together and give rise to a compact structure. The lower leaves of the bud are older and larger than those higher up. A cabbage cut longitudinally gives a good idea of a bud—the development of the leaves in *acropetal* succession and the condensed shoot with the growing apex. The normal position of a bud is at the apex of the stem or the branch and in the axil of a leaf. The bud, in the former case, is known as the **terminal** or **apical bud,** and in the latter case as the **axillary bud.** As the terminal bud grows the stem elongates, and as the axillary bud grows it gives rise to a branch, the bud itself then occupying the terminal position. When the gardeners prefer a bushy habit of a plant to its tallness they prune it thus removing the terminal buds. Buds may be **vegetative buds** or **floral buds,** according as they develop into branches with leaves or into flowers. Sometimes some extra buds develop by the side of the axillary bud; these are known as the **accessory buds.** As said above, the apex of the stem and the axil of the leaf are the normal positions of buds, but they may also sometimes be seen

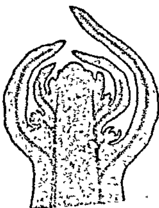


FIG. 51. A bud in longitudinal section

to arise irregularly at various other parts of a plant such as the root (radical buds), as in sweet potato, or the leaf (foliar buds), as in sprout leaf plant (*Bryophyllum*, see fig. 34), elephant ear plant (*Begonia*; see fig. 35), *Scilla*, walking fern (*Adiantum*; see fig. 506), *Kalanchoe* (see fig. 509), and water lily (*Nymphaea*), or at different positions of the stem and the branches (cauline buds). Such buds are known as **adventitious** because of their abnormal position. When a tree is pollarded adventitious buds are seen to appear all round the cut surface. All these buds have the power of gradually developing into new branches, and in some cases into independent plants. Buds may be *active* or *dormant*. In the former case buds begin to grow and develop as soon as they emerge from the stem. In the latter they remain inactive for a period, and only later do they begin to grow and develop. This is their dormant or sleeping condition. Buds of some plants are seen to be covered in their earlier stage by a number of scaly leaves which protect them from sun and rain; such buds are said to be *scaly*. When there is no such covering over them they are *naked*.

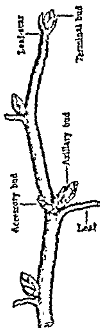
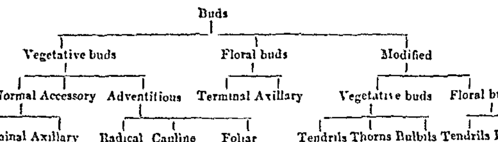


FIG. 52. Buds.

Protection of the Bud. Since buds have to give rise to flowers, leaves and branches it is imperative that these should be protected against external injuries—sun, rain, fungi, insects, etc., and this protection is afforded in different ways. (1) The young leaves of the bud normally overlap each other, and remain variously rolled or folded to protect themselves and the growing apex against sun and rain. (2) They may be covered by hairs, or in some cases they remain bathed in resinous or gummy secretions. (3) They remain enclosed in some dry and scaly outer leaves, called **bud-scales**, as in banyan, jack, *Magnolia*, *Mesua* (B. NAGESWAR; H. NAGKESAR), etc. (4) There may be a coating of wax or cutin on the leaf-surface to check evaporation of water and to prevent the leaves and the growing apex from getting wet.

Modification of the Bud. Vegetative buds may be modified into tendrils (see fig. 59), as in passion-flower and vine, or into thorns (see fig. 87), as in *Duranta* (B. DURANTA-KANTA; H. NIL-KANTA), wood-apple, etc. Sometimes these may become modified into special reproductive bodies, known as **bulbils** (see p. 57). Floral buds may likewise be modified into tendrils (see figs.

83-4), as in Sandwich island climber and balloon vine (B. KAPAL-PHUTKI), or into bulbils (see p. 57) for the purpose of reproduction.



Outgrowths of the Shoot

(1) **Hairs.** These are outgrowths developing from the surface-layer of the shoot (stem, leaf and flower) and are of various kinds (a) **shoot-hairs or trichomes** (see fig 31); (b) **stinging hairs** (see fig 181), as in nettles; (c) **glandular hairs** (see fig. 415), as in tobacco, *Plumbago* (B. CHITA; H. & P. CHITRAK) and hogweed (*Boerhaavia*; B. PUNARNAVA; H. THIKRI); (d) **special sensitive hairs** (trigger hairs), as in Venus' fly-trap (see fig. 434); and (e) **bristles** (see p 93), as in many cacti.

Functions of Hairs: (a) shoot-hairs are mostly cutinized and as such they check excessive evaporation of water and radiation of heat, prevent the plant from being wetted by rains and also protect the plant against intense illumination (i.e very strong sunlight); (b) a dense coating of hairs serves to protect the plant against the attack of grazing animals; protection of this nature is better afforded by glandular hairs, stinging hairs and bristles; (c) hairs developing on seeds and fruits aid in their distribution by wind; (d) hooked hairs assist the plant to climb; and (e) special sensitive hairs on the leaf of Venus' fly-trap help it to close up suddenly and capture insects.

(2) **Emergences.** These are stronger outgrowths than the hairs and are also more deep-seated; a few outer layers take part in their formation. But like the hairs these are more or less irregularly distributed Emergences may be: (a) **prickles** (see p 39), as in rose and cane (figs. 57 8); (b) **scales** (see p. 80; [illegible] fig. 67); [illegible] at the junct[illegible] nd (d) tentac[illegible]

HABIT OF THE PLANT

The nature of the stem, the height the plants attain, and the duration and mode of their life determine their habit.

1. **Herbs.** These are small plants with soft stems. According to their duration of life these may be classified as (1) **annuals,** (2) **biennials,** and (3) **perennials.** (1) **Annuals** are those plants that attain their full growth in one season, living for a few months or at the most for one year only. Within this period they produce flowers and seeds and then die off at the end of the season. Common examples are sunflower, mustard, rice, jute, lady's finger, pea, bean, etc. (2) B[illegible] are those plants that live for two years. They attain their [illegible] vegetative growth in the first year and they produce flowers

seeds in the second year after which they die off. Common examples are cabbage, radish, beet, carrot, turnip, etc. (in the tropical climate they behave like annuals); and (3) **perennials** are those plants that persist for a number of years; the aerial parts of such plants may die down every year at the end of the season after producing flowers and seeds but new shoots develop again from the underground stem after a few showers of rains, e.g. *Canna*, ginger, banana, arrowroot, *Alpinia* (B. TARA), etc.

2. **Shrubs.** These are medium-sized plants with hard and woody stem which branches profusely from near the ground so that the plants often become bushy in habit without having a clear trunk. They are larger than herbs, but much smaller than trees, e.g. China rose, garden croton, night jasmine (B. SHEPHALIKA; H. HARSINGHAR), *Duranta*, etc.

3. **Trees.** These are very tall plants with a clear trunk and have hard and woody stem and branches, e.g. mango, jack, teak, beef-wood tree (*Casuarina*; B. & H. JHAU), country almond, etc. Shrubs and trees are perennial.

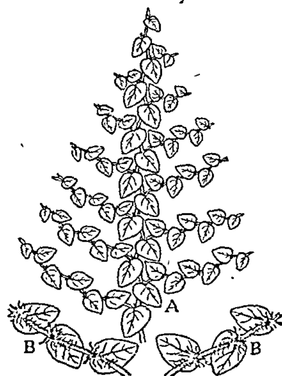


FIG. 53. Indian ivy (*Ficus pumila*)—a rootlet climber; *A*, upper side; *B*, lower side.

4. **Climbers.** These have thin and long stem with diffuse branches; they often develop special organs of attachment by which they cling to neighbouring objects for the support of their body and for assistance in climbing. Climbers may be classified according to the mode of climbing they have adopted.

(1) **Rootlet Climbers.** These are plants which climb by means of small adventitious roots (fig. 53) given off from their inner side or from their nodes as they come in contact with a supporting plant or any suitable object. Such roots either

form small adhesive discs or claws which act as *holdfasts* or they secrete a sticky juice which dries up fixing the climbers to their support. Examples may be seen in betel (*Piper betle*; see fig. 48), long pepper (*Piper longum*), *Piper chaba* (B. CHAI; H. CHAB), *Scindapsus* (B. GAJPIPAL; H. HATIPIPLI), ivy (*Hedera helix*), Indian ivy (*Ficus pumila*; fig. 53), wax plant (*Hoya*), *Pothos*, etc. Twining parasites produce special roots, called haustoria, which not only suck the host plant, but also at the same time fix the parasitic plants to their host and thus help them in twining, e.g. dodder (*Cuscuta*; see fig. 65).

(2) **Hook Climbers.** The flower-stalk of *Artabotrys* (B. KANTALI-CHAMPA; H. KANTELI-CHAMPA) produces a curved hook (fig. 56), which facilitates to some extent the climbing of the branches. Often **prickles** and **thorns** (see p. 56) are curved and hooked in certain plants. Thus in cane (*Calamus*; fig. 57) a long slender axis beset with numerous sharp and curved hooks is produced from the leaf-sheath. This axis pushes through the surrounding bushes and branches of neighbouring trees, and sticks there supporting the weight of the plant. In this way many canes—rattan canes, for example—have been seen to climb neighbouring shrubs and trees in forests and grow to a length of 500-600 ft. Climbing rose (fig. 58) and *Pisonia* (B. BAGH-ANCHRHA) are provided with numerous curved prickles for the purpose of climbing (and also for self-defence). Glory of the garden (*Bougainvillea*; B. BAGAN-BILAS—fig. 54) often produces curved thorns which are used as organs of support for climbing. *Uncaria* (fig. 55), a large climbing shrub,

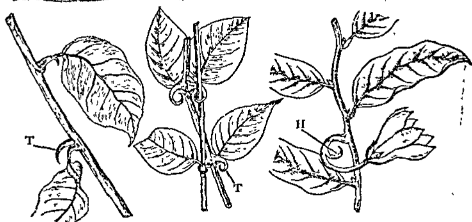


FIG. 54 FIG. 55 FIG. 56

Hook and Thorn Climbers. Fig. 54. Glory of the garden (*Bougainvillea*); *T*, thorn. Fig. 55. *Uncaria*; *T*, hooked thorn. Fig. 56. *Artabotrys*; *H*, *hook*.

also climbs by curved hooks (thorns). These hooks after clasping an object continue to grow, and become hard and woody.

(3) **Tendril Climbers.** These are plants which produce slender, leafless, spirally-coiled structures, known as **tendrils**, and

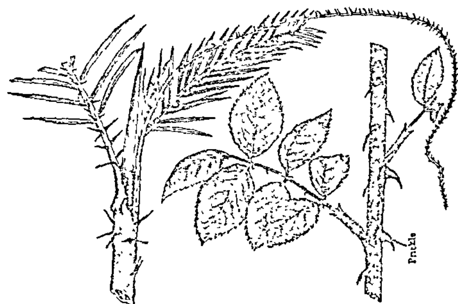
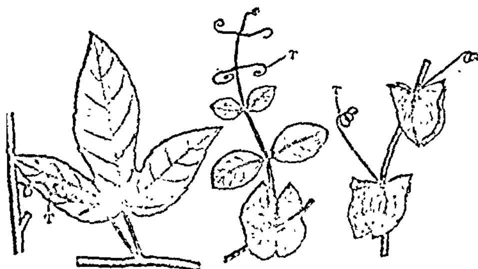


FIG. 57 FIG. 58
Prickle Climbers. Fig. 57. Cane. Fig. 58. Rose.

climb objects with the help of them ; tendrils twine themselves round some support, and help the plants concerned to support



balloon vine (*Cardiospermum*; B. KAPAL-PHUTKI or SHIBJHUL—see fig. 84), etc., or of leaves, as in pea (fig. 60), wild pea (*Lathyrus*; fig. 61), etc., or of stipules, as in *Smilax* (B. KUMARIKA; H. CHOBCHINI—see fig. 113).

(4) **Leaf Climbers.** The petiole (i.e. the leaf-stalk) of virgin's bower (*Clematis*; H. BELKUN—fig. 62) and that of



Fig. 62 Fig 63 Fig. 64

Leaf Climbers Fig 62. Virgin's bower (*Clematis*). Fig. 63. Glory lily (*Gloriosa*). Fig. 64. Pitcher plant (*Nepenthes*; see also figs. 152-3).

garden nasturtium are sensitive to contact with a foreign body.
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and slender stem and branches; they climb by twining bodily round trees, shrubs and hedges, e.g. country bean, railway creeper, butterfly pea (B. APARAJITA; H. APARAJIT), Indian spinach (*Basella*; B. PUIN; H. POI), Rangoon creeper (B. SANDHYA-MALATI; H. LAL-MALTI), *Quamoclit* (B. KUNJALATA; H. KAMLATA), Indian liquorice or crab's eye (*Abrus*; B. KUNCH; H. & P. RATTI), etc. Twiners have no special organs of attachment like the climbers proper. Some of the climbers twi
B.
e.g
while others are indifferent in their direction of movement.

(6) **Lianes.** These are very thick and woody, perennial climbers, commonly met with in forests. They twine themselves round tall trees in search of sunlight, and ultimately reach their top. There they get plenty of sunlight and produce a canopy of foliage. Common examples are *Hiptage* (B. MADHABI-LATA; H. MADHU-LATA; P. MADULATA), camel's foot climber (*Bauhinia vahlii*; B. LATA-KANCHAN or CHEHUR; H. CHAMBULI; P. TAUR—see fig. 343), cowage (*Mucuna*; B. ALKUSHI; H. & P. KAWANCH) and some species of fig. (*Ficus*).

Stems

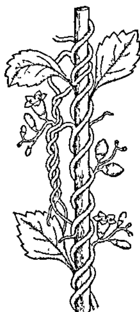
- Strong
  - Excurrent, e.g. mast tree.
  - Deliquescent, e.g. banyan.
  - Caudex, e.g. palms.
  - Culm, e.g. bamboo.
  - Scape, e.g. tuberose.
- Weak
  - Trailing
    - (a) Prostrate, e.g. *Basella*.
    - (b) Decumbent, e.g. *Tridax*.
    - (c) Diffuse, e.g. *Boerhaavia*.
  - Creeping, e.g. dog grass.
  - Climbing.
    - Climbers
      - Rootlet-, e.g. betel.
      - Hook-, e.g. *Artabotrys*.
      - Tendril-, e.g. passion-flower.
      - Leaf-, e.g. *Clematis*.
      - Twiner, e.g. bean.
      - Liane, e.g. *Hiptage*.

SPECIAL TYPES OF PLANTS

Green plants normally prepare their own food with the help of chlorophyll contained in them and nourish themselves. There are, however, many plants which have to depend on a supply of food from different sources and the mode of nutrition in them is also different. Some of them are non-green in colour and are, therefore, obliged to lead a parasitic or saprophytic life (see below), while others, although green, get their supply of food, partially at least, from sources other than the soil. Such plants may be of the following types:

1. **Parasites.** These are plants that grow upon other living plants or animals and absorb their food material from them. For the purpose of absorption parasites produce special roots, called *sucking roots* or *haustoria*, which penetrate into the tissue of the host plant or animal and suck it, i.e. absorb nutriment from it. There are d[illegible]
Some are *total parasites* and c[illegible]
total parasites are never green in [illegible]
food from the host plant; while the partial (or semi-) parasites develop chlorophyll and are in a position to manufacture food material for themselves to a greater or less extent. They may be parasitic on the stem and branches or on roots. Accordingly they are said to be *stem-parasites* or *root-parasites*. The follow-

ing are some of the common examples of different types of parasites:



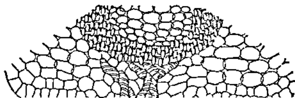
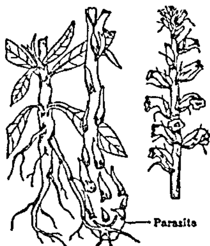


FIG. 65 FIG. 66

Fig. 65. Dodder (*Cuscuta*)—a total stem parasite. Fig 66. A section through dodder (and the host plant) showing the sucking root (haustorium).



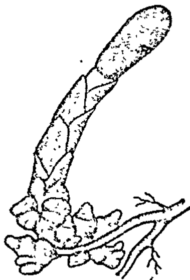


FIG. 67 FIG. 68

Fig. 67. Broomrape (*Orobanche*)—a total root-parasite. Fig. 68. *Balanophora*—a total root-parasite.

(1) Total stem-parasites, e.g. dodder (*Cuscuta*; B. SWARNALATA; H. AKASHBEL; P. AMARBEL—fig. 65).

(2) Partial stem-parasites, e.g. mistletoe (*Viscum*; B. BANDA; H. BHANGRA—fig. 69), *Loranthus* (B. MANDA; H. BANDA) and *Cassytha* (B. AKASH-BEL; H. AMARBELI; P. AMIL).

(3) Total root-parasites, e.g. broomrape (*Orobanche*; B. BANIA-BAU; H. SARSON-BANDA—fig. 67)—parasitic on roots of potato, tomato, brinjal, mustard, tobacco, etc., and often does a considerable damage to these crops, *Balanophora* (fig. 68)—parasitic on tree roots, common in the forests of Assam, and *Rafflesia*—parasitic on *Vitis* roots in Java and Sumatra.

(4) Partial root-parasites, e.g. sandalwood tree (*Santalum*)—found abundantly in Mysore.

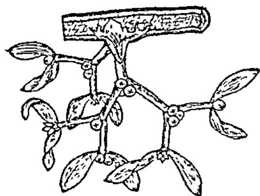


FIG. 69. Mistletoe—a partial stem-parasite

Rafflesia (fig. 70) is a very interesting plant, inasmuch as it bears the most gigantic flower in the world, which often measures 3—5 feet in diameter and weighs in some cases over 18 lbs. It is parasitic on roots of *Vitis*, figs, etc. The peculiar feature of the plant is that the stem has become reduced to a thread-like structure which passes through the root of the host plant and draws nutriment from the latter, and here and there on the surface of the ground close to the host plant, as if borne by it, the parasite produces flowers of this gigantic size. The plant was first discovered in 1818 by Sir Stamford Raffles, while making a tour in the interior of Sumatra, and was named after him. Altogether six species have been discovered in Sumatra, Java and the neighbouring islands. The flower is of a livid, fleshy colour, and the smell is like that of putrid meat.

Parasitic Fungi and Bacteria. Among the lower forms of plants, particularly fungi and bacteria, there are many parasites infecting either plants or animals. Frequently such parasites attack many useful plants and agricultural crops and do considerable damage to them, e.g. wheat rust, potato blight, corn smut, leaf mildew, etc. Not infrequently they attack animals, e.g. water mould (*Saprolegnia*) attacking fish, ringworm fungus (*Microsporon*) causing ringworm, and many parasitic bacteria causing various diseases.

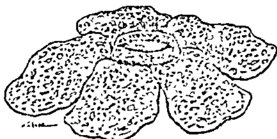


FIG. 70 *Rafflesia*—a total root-parasite.

2. **Epiphytes** (*epi*, upon; *phyta*, plants). These are plants that grow upon other plants (see fig. 50), but do not suck them.

i.e. do not absorb food from them, as do the parasites. They usually develop three kinds of roots, viz. *clinging roots*, *absorbing roots* and *hanging roots*. The clinging roots grow into cracks and crevices in the bark of the supporting plant and fix the epiphyte in proper position on the branch; besides, they act as reservoirs of humus which accumulates in the network formed by such roots. The absorbing roots developing from the clinging roots project into the humus and draw food from it. The hanging roots are provided with an outer covering of a special absorptive tissue, called velamen (fig. 71), which usually consists of [illegible] cells. The cells are dead [illegible] their walls develop fibrous [illegible] te pits in the walls. The velamen acts as a sort of sponge and absorbs moisture from the surrounding air and also water trickling down the root.

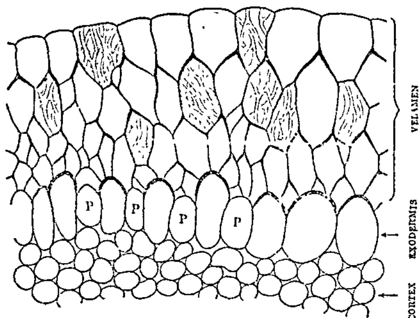


FIG. 71. Velamen of *Vanda* (an epiphytic orchid) root in transection; *P*, passage cell.

Examples are found in many orchids, e.g. *Vanda* (B. & H. RASNA) and some ferns. Banyan, peepul, etc., are, in their earlier stages, often epiphytic on date-palm and other trees.

3. S[illegible] These are plants th[illegible] tance of vegeta[illegible] fr[illegible] them. Fungi and bacteria are either parasites or saproph[illegible] Among the 'flowering' plants Indian pipe (*Monotropa*; fig. [illegible] and some orchids afford good examples of saprophytes. M

tropa grows in the Khasi hills at an altitude of 6,000—8,000 feet. Total saprophytes are *colourless ; and the partial ones* are green in colour. Their roots become associated with a filamentous mass of a fungus which takes the place of and acts as the root-hairs, absorbing food material from the decomposed organic substances present in the soil. The association of a fungus with the root of a higher plant is known as **mycorrhiza.**

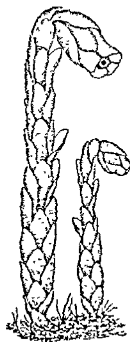


Fig. 72 Indian pipe (*Monotropa*)—a saprophyte.

4. **Symbionts** (*syn*, together; *bios*, life). When two organisms live together, as if *these are parts of the same plant,* and are of mutual help to each other these are called **symbionts,** and the relationship *between the two is expresed as* **symbiosis.** Lichens (see Chapter V, Part V) are typical examples. These are associations of algae and fungi, and commonly occur as thin round greenish patches on tree-trunks and old walls. The alga in a lichen being green prepares food and shares it with the fungus, while the latter absorbs water and mineral salts from the surrounding medium, and also affords protection to the alga. Among the 'flowering' plants some of the mycorrhizas are good examples of symbiosis. Mycorrhizal fungi are commonly associated with the roots of many forest trees, orchid seedlings, pine seedlings, etc. The fungus concerned absorbs water, mineral salts and nitrogenous organic compounds from the soil, while in return it receives food from the root. The asso*ciation of nitrogen-fixing* bacteria (nodule bacteria ; see fig. 463) with the roots of leguminous plants (e.g. pulses) is another example of symbiosis, and so also are the associations of certain *algae and bacteria in the root-cortex of cycad.*

Mycorrhiza. Mycorrhiza (fungus root) is the association of a fungus with the root of a higher plant. This association is often a [illegible] ure in many species *of plants*, particularly forest trees (beech, o[illegible] conifers (pine, etc.), saprophytic phanerog[illegible] seedl[illegible] fungus concerned may belong to various [illegible] infe[illegible] not elongate but frequently it branches [illegible] *formed. Two types of mycorrhiza* are [illegible] fungus is internal, usually living withi[illegible] in many orchids, and (b) *ectotro*[illegible] external, growing attached to the [illegible] *conifers* and most other plants [illegible] mycorrhiza in which the fungus growing out[illegible]

The biological relationship between the fungus and the root is not very clear in all cases. The opinion in this respect is divergent. The relation ship may range from true parasitism to genuine symbiosis. In the latter case the fungus absorbs water, mineral salts and nitrogenous organic substances from the soil, and in some cases it even fixes free nitrogen of the air. The fungus also helps respiration of the root, as in pine. In return it receives food from the root. The mycorrhizal fungus particularly benefits certain plants. Thus it is seen that orchid seeds do not germinate if these are not infected by a particular fungus, and the pine seedlings and orchid seedlings are slow in growth and become weak in the absence of a similar infection.

5. **Carnivorous Plants** (see Chapter VII, Part III). Carnivorous plants are those that capture insects and small animals, and feed upon them absorbing only the nitrogenous compounds from their bodies. Such plants are green in colour and prepare their own carbonaceous food, while they partially depend on insects and other animals for nitrogenous food. Some of the examples are sundew, butterwort, Venus' fly-trap, *Aldrovanda*, pitcher plant and bladderwort (see figs. 482-8).

MODIFICATIONS OF STEMS

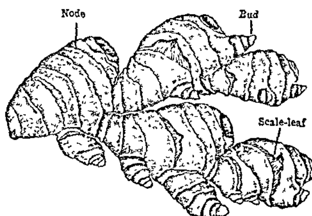
Stems or branches of certain plants, instead of growing vertically upwards and bearing leaves and flowers like the normal stem, are modified into various shapes to carry on special functions. The main functions that such modified stems carry o[illegible] year to year through b[illegible]; (b) vegetative pro- p[illegible] branches spreading out in different directions; and (c) specialized funstions by certain metamorphosed aerial organs. Thus in response to the above functions stems undergo modifications into different forms, each to meet a special need. The various modifications may be discussed under the following heads: underground modifications, sub-aerial modifications and aerial modifications or metamorphoses.

I. Underground Modifications of Stems

For the purpose of perennation stems develop underground and lodge there permanently, lying in a dormant, defoliated condition for some time and then giving off aerial shoots annually under favourable conditions. They are always thick and fleshy, having a heavy deposit of reserve food material in them. Developing underground they simulate roots in their general appearance, in being non-green in colour and in lying buried in the soil, but are readily distinguished from the latter by the presence of (a) nodes and internodes, (b) scale-leaves, and (c) buds (axillary and terminal). The main function of this group of modified stems is, as already stated, (a) perennation;

but they are also meant (*b*) to store up food material and (*c*) to propagate, i.e. to multiply plants vegetatively. The various types met with in this group are as follows:—

1. **Rhizome** (fig. 73). Rhizome is a prostrate, thickened stem, creeping horizontally under the surface of the soil. It is provided with distinct nodes and long or short internodes; it bears some scaly leaves at the nodes; it possesses a bud in the axil of the scaly leaf; and it ends in a terminal bud. Some slender, adventitious roots are given off from its lower side. The rhizome may be unbranched or sometimes the axillary buds grow out into short, stout branches. It remains dormant underground and then with the approach of vegetative season the terminal bud grows into the aerial shoot. Sometimes, the branches themselves are separated off, each growing into a new independent plant. With the close of the season or after flowering the aerial parts die down every year, and in the following year growth is carried on by one or more lateral buds and thus it continues to grow year after year. Its direction is normally horizontal, but sometimes it grows in the vertical direction (root-stock), as in *Alocasia* (B. MAN-KACHU; H. MAN-KANDA). Examples of rhizome are seen in *Canna*, ginger, turmeric, arrowroot, water lily, lotus, ferns and many aroids.

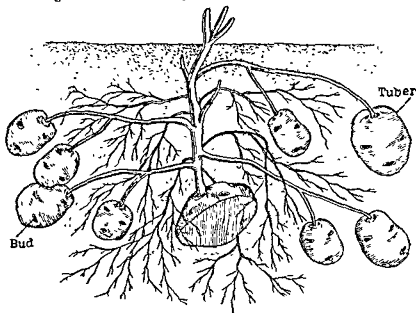


Underground Modified Stem. FIG. 73. Rhizome of ginger.

2. **Tuber** (fig. 74). It is the swollen end of a special

deposit of food material, so much so that it becomes almost spherical, e.g. potato. Jerusalem artichoke (B. HATICHOKE) is another example.

Development and Morphological Nature of Potato Tuber. Potato tuber is a stem structure. At first an axillary bud on the underground portion of the stem grows into a slender, more or less horizontal branch (really a



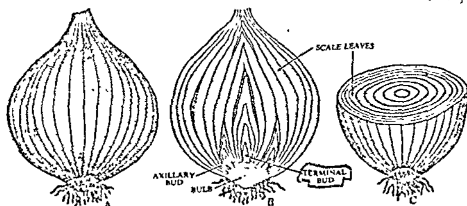
Underground Modified Stem (*contd.*). FIG. 74. Tubers of potato.

stolon). This branch is provided with nodes and internodes, scaly leaves, and also a terminal bud. Soon its growth ceases. But still there is steady flow of food from the green aerial parts to this branch, accumulating at its tip which gradually becomes enlarged, often finally becoming almost spherical. This enlarged tip of the underground branch is a tuber. Like the branch itself the tuber is provided with buds (commonly called 'eyes'), each in the axil of a scaly leaf which develops at the node, and there is a terminal bud, too. Besides, a spiral arrangement of scaly leaves or buds ('eyes'), as in the stem or branch, may be made out more easily in an elongated tuber. All this points to the stem nature of a potato tuber. It has also the internal structure of a stem.

Stem-tuber and Root-tuber. Both these structures lie underground and look alike, but (*a*) a stem-tuber develops exogenously from the node of the stem in the axil of a scale-leaf, has nodes and internodes, and bears buds in the axils of scale-leaves for vegetative propagation; while a root-tuber or tuberous root (see pp. 27 & 28) develops adventitiously from any part of the stem, as in sweet potato, or as a modification of the tap root, as in four o'clock plant, and is without nodes and internodes, scale-leaves and buds. In sweet potato, however, a few buds without scale-leaves are seen scattered on the root; (*b*) a stem-tuber has the internal structure of a stem; while a root-tuber has the internal structure of a root. We conclude, therefore, that a stem-tuber is a stem structure, being an underground modification of it, and a root-tuber is a root structure, being a modification of an adventitious root or of a tap root.

3. **Bulb** (fig. 75). It is a [illegible]
stem. It consists of a short co[illegible]
disc from the upper surface o[illegible]
(which are the swollen bases
some outer dry scale-leaves, while adventitious (fibrous) roots are given off from its base. The scale-leaves, often simply

called scales, may occur completely surrounding the bulb in concentric rings, as in onion, leek, garlic, tuberose, most lilies, etc., or they may be narrow partially overlapping each other by their margins only, as in certain lilies. The former type of bulb is most common and is said to be *tunicated* or *coated,* while the latter is rather rare and is said to be *scaly.*



Underground Modified Stem (*contd.*). Fig 75 Bulb of onion. *A*, an entire onion showing the lower part of the bulb with adventitious roots, and outer dry scale-leaves with distinct veins; B, an onion cut longitudinally; and C, an onion cut transversely.

The fleshy scales store food (sugar, etc.), while the dry scales give protection. The bulb is vertical in direction and the terminal bud of it gives rise to the aerial shoot. Some axillary buds may also be produced in the axils of fleshy scales. These may develop into aerial shoots and finally form daughter bulbs or they may remain dormant. The daughter bulbs grow in the following season.

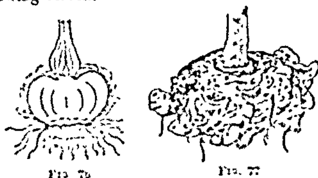


Fig 76 Fig. 77

and ... nd stem growing in tl ... ounded in shape or often somewhat flattened from top to bottom. It contains a heavy deposit of food material and often grows to a considerable size. It bears one or more buds in the axils of scale-leaves, and some of these buds grow up into daughter corms. Adventitious roots normally develop from the base but sometimes also from the sides. Corm is found in *Amorphophallus* (B. OL; H. KANDA), taro (*Colocasia*; B. KACHU; H. & P. KACHALU), *Gladiolus*, saffron (*Crocus*) and meadow saffron (*Colchicum*). Both kinds of saffron are cultivated in Kashmir.

A corm becomes fully formed only after the flowering is over One corm is formed a year, and two or three corms may be produced one upon the other in two or three successive years, the old one, of course, shrivelling up to a great extent. A terminal bud is produced in spring, which develops into the aerial shoot. Lateral buds may also be produced in the axils of scales, each developing into a daughter corm The daughter corms subsequently separate and develop into new plants.

II. Sub-aerial Modifications of Stems

For the purpose of vegetative propagation some of the lower dormant buds of the stem in certain plants grow out into slender, lateral branches which according to their origin, nature and mode of propagation have received different names. Some of them are sub-aerial, spreading on the surface of the soil, and others partly subterranean. The various kinds are runner, stolon, offset and sucker. Propagation by such modified branches is sometimes so rapid that within a short time a large area is covered by the progeny.

1. **Runner** (fig. 78). It is a slender, prostrate branch with ...

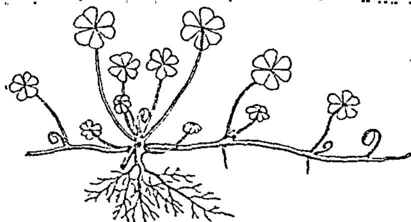


FIG. 78. Runner of wood-sorrel (*Oxalis*).

grows into a new plant. Many such runners are often produced by the mother plant and they spread out on the ground on all sides. They may break off from the mother plant and grow up as independent daughter plants. Runners are meant for vegetative propagation. Examples are seen in wood-sorrel (*Oxalis*; B. AMRUL-SAK; H. CHUKA-TRIPATI; P. KHATTI-BUTI), *Marsilea* (B. SUSHNI-SAK), strawberry (*Fragaria*), Indian pennywort (*Centella=Hydrocotyle*; B. THULKURI; H. & P. BRAHMIBOOTI—see fig. 507), etc.

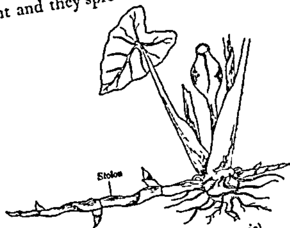


FIG. 79 Stolon of taro (*Colocasia*).

2. **Stolon** (fig. 79). It is a shoot produced at the basal part of the stem buried in the soil and it grows horizontally outwards into a long or short, slender, underground branch. The branches grow out in different directions and at length their end (terminal bud) emerges out of the ground and develops into a new plant. Such an underground branch is known as the stolon. The stolon resembles a runner in all respects excepting that it is subterranean, while the runner is sub-aerial. Examples of stolon are seen in taro (B. KACHU; H. & P. KACHALU), arrowroot, passion-flower, some jasmines, dragon plant (*Dracaena*), sandal rose, *Tecoma grandiflora*—an ornamental garden climber.

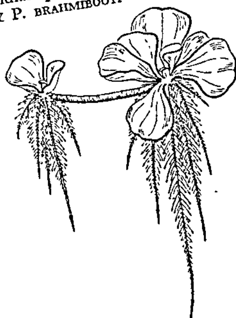


FIG. 80. Offset of water lettuce (*Pistia*).

3. **Offset** (fig. 80). Like the runner it originates in the axil of a leaf as a short, more or less thickened, prostrate

tuft of leaves above and a
ne offset often breaks away
the daughter plant embarks
on a separate career. Common examples are water lettuce (*Pistia*; B. PANA; H. JAL-KHUMBI) and water hyacinth (B. KACHURI-PANA). An offset is shorter and stouter than a runner, and is found only in the rosette type of plants.

4. **Sucker** (fig. 81). Like the stolon the sucker is also a lateral branch developing from the underground part of the stem. But it grows obliquely upwards and directly gives rise to a leafy shoot or a new plant. Occasionally it grows horizontally outwards only to a certain extent, but soon it turns up. A sucker is always much shorter than a stolon. The sucker strikes roots at the base either before it separates from the mother plant or soon after. It is meant for vegetative propagation of the plant. Examples of sucker are seen in *Chrysanthemum* (B. CHANDRA-MALLIKA; H. GULDAUDI), rose, mint (B. PUDINA; H. PODINA), peppermint, dagger plant (*Yucca*), etc.

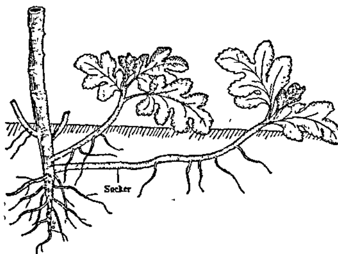


FIG. 81 Suckers of *Chrysanthemum*.

III. Aerial Modifications: Metamorphoses

Vegetative and floral buds which would normally develop into branches and flowers, often undergo extreme degree of modification (metamorphosis) in certain plants for definite purposes. Metamorphosed organs are stem-tendril for climbing, thorn for protection, phylloclade for food manufacture, and bulbil for vegetative reproduction.

1. Stem-tendril (figs. 82-5). It is a thin, wiry, leafless, spirally-curled branch, by which climbers attach themselves to

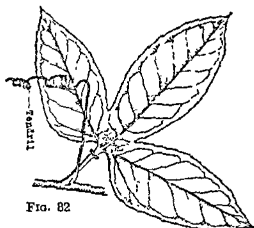


Fig. 82



Fig. 83

Stem-tendrils. Fig. 82. Tendril of passion-flower (*Passiflora*). Fig. 83. Tendrils of Sandwich island climber (*Corculum*). *T*, a tendril.

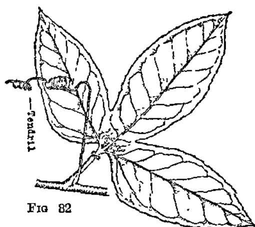
neighbouring objects and climb them. Stem-tendrils are seen in vine (*Vitis*), passion-flower (*Passiflora* ; B. & H. JHUMKA-LATA), Sandwich island climber (*Corculum*), etc. The tendril is always a climbing organ, and as such it is found only in the climbers. It may sometimes bear some small scaly leaves and not infrequently it becomes branched.



Fig. 84. Tendrils of balloon vine (*Cardiospermum*). *T*, a tendril

That the stem-tendril is a modification of a stem (branch), is evident from the fact that it arises in the axil of a leaf or at the apex of a branch. Thus in passion-flower the axillary bud is modified into the tendril, and in *Vitis* it is the terminal bud that becomes so modified. Sometimes, as in Sandwich island climber (*Corculum*) and balloon vine (*Cardiospermum* ; B. KAPAL-PHUTKI or SHIBJHUL—fig. 84), floral buds are modified into tendrils. In *Gouania*, an extensive climber, many of the branches end in strong tendrils (fig. 85)

1. **Stem-tendril** (figs. 82-5). It is spirally-curled branch, by which climbe



Stem-tendrils. Fig. 82. Tendril of passion-flow Tendrils of Sandwich island climber (*Corcu*

neighbouring objects and climb them. Ste vine (*Vitis*), passion-flower (*Passiflora* ; B Sandwich island climber (*Corculum*), etc.



Fig 84. Tendrils of balloon vine (*Cardiospermum*). *T*, a tendril.

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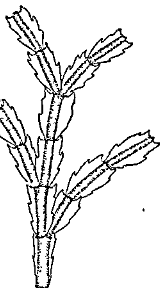


FIG. 88 FIG 89 FIG. 90

Phylloclades. FIG. 88. Prickly pear (*Opuntia*). FIG. 89. Cocoloba. FIG. 90. *Epiphyllum*.

of as the cladode (fig. 91), as in *Asparagus* (B. SATAMULI; H. & P. SATAWAR). Duckweed (*Lemna*; see fig. 23) is another common example of cladode. The phylloclade of cacti and other desert plants is an adaptation to desert conditions. In such plants the transpiratory surface is reduced to a minimum owing to uncertain supply of water in deserts. The cladode of *Asparagus* is also a similar adaptation.

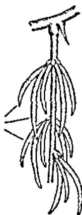
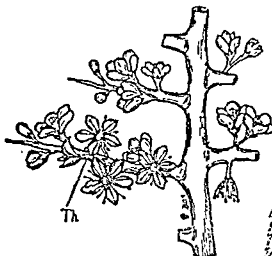


FIG. 91. Cladodes of *Asparagus*.

3. **Bulbil** (see figs. 510-3). Bulbil is a special multicellular body essentially meant for the reproduction of the plant. It may be the modification of a vegetative bud or of a floral bud. In any case it sheds from the mother plant and grows up into a new independent one. In wild yam (*Dioscorea*; B. GACHH-ALOO; H. ZAMINKHAND—see fig. 511) the bulbil occurs as a fleshy axillary body, while in wood-sorrel (see fig. 513) a large number of small bulbils occur on the top of the tuberous root. In *Globba* (see fig. 510), American aloe (*Agave*; see fig. 512) and onion, however, bulbils are seen to occur on the inflorescence, being modifications of some flowers.

the stem or the branch. Other common examples are wood-apple (*Aegle*), lemon, pomegranate, *Vangueria* (B. MOYENA; H. MOINA), *Prinsepia* (H. & P. BHEKAL—see fig. 133), etc.



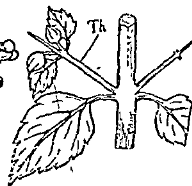


FIG. 86 FIG. 87

Thorns. FIG. 86. Thorns of prune (*Prunus*) *Th*, thorn. FIG. 87. Thorns of *Duranta*. *Th*, thorn.

T[illegible]

[illegible]

[illegible]

[illegible]

—see fig. 54.)

Differences between Thorns and Prickles. Both thorns and prickles (see p. 92) are primarily defensive organs being sharp and pointed; they also sometimes act as climbing organs. Their morphological differences are: a thorn is a modification of an axillary bud or sometimes of a terminal bud, as in *Carissa* (B. KARANJA; H. KARONDA) and frequently bears leaves, flowers and fruits, and is often branched; whereas a prickle is a mere outgrowth, never bears leaves, flowers and fruits, and is unbranched. A thorn is axillary in position; whereas a prickle is irregular in distribution occurring in any part of the stem, branch or even leaf. Further a thorn is deep-seated; while a prickle is superficial in origin. Thorn is found in wood-apple, *Duranta*, etc., and prickle in rose, coral tree, etc.

3. **Phylloclade** (figs. 88-90). Phylloclade is a green, flattened or rounded stem. Being green it carries on the functions of the leaves which are seen to be either feebly developed or modified into spines. Examples are found in many cacti (sing. cactus) such as prickly pear (*Opuntia*; B. PHANI-MANSHA; H. NAGPHANI), night-blooming cacti (*Cereus* and *Phyllocactus*) and *Epiphyllum*. Other common examples are cocoloba (fig. 89), beef-wood tree (*Casuarina*; B. & H. JHAU), *Euphorbia* (B. & H. SIJ), etc. The phylloclade of one internode is spoken







FIG. 88 FIG. 89 FIG. 90

Phylloclades. FIG. 88. Prickly pear (*Opuntia*). FIG. 89. Cocoloba. FIG. 90. *Epiphyllum*.

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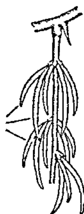


FIG. 91. Cladodes of *Asparagus*.

3. **Bulbil** (see figs. 510-3). Bulbil is a special multicellular body essentially meant for the reproduction of the plant. It may be the modification of a vegetative bud or of a floral bud. In any case it sheds from the mother plant and grows up into a new independent one. In wild yam (*Dioscorea* ; B. CACHH-ALOO ; H. ZAMINKHAND—see fig. 511) the bulbil occurs as a fleshy axillary body, while in wood-sorrel (see fig. 513) a large number of small bulbils occur on the top of the tuberous root. In *Globba* (see fig. 510), American aloe (*Agave* ; see fig. 512) and onion, however, bulbils are seen to occur on the inflorescence, being modifications of some flowers.

Modifications of Stems

- Underground
  - —Rhizome, e g ginger
  - —Tuber, e g potato.
  - —Bulb
    - —Scaly, e g , some lilies
    - —Tunicated, e g onion
  - —Corm, e.g *Amorphophallus*
- Sub-aerial
  - —Runner, e g wood-sorrel.
  - —Stolon, e.g. taro.
  - —Offset, e.g *Pistia*
  - —Sucker, e g. *Chrysanthemum.*
- Aerial (Metamorphoses)
  - —Tendril, e.g. passion-flower and vine.
  - —Thorn, e.g. *Duranta.*
  - —Phylloclade, e.g cacti.
  - —Cladode, e g. *Asparagus.*
  - —Bulbil, e.g. *Globba* and *Dioscorea.*

BRANCHING

The mode of arrangement of the branches on the stem is known as **branching.** There are two principal types of branching, viz. **lateral** and **dichotomous.**

A. Lateral Branching. When the branches are produced laterally, that is, from the sides of the main stem, the branching is called **lateral.** The lateral branching may be **racemose** or indefinite or monopodial (*monos*, one ; *podos*, foot or axis) and **cymose** or definite.

I. Racemose Type. Here the growth of the main stem is indefinite, that is, it continues to grow indefinitely by the terminal bud and give off branches laterally in *acropetal* succession, i.e. the lower branches are older and longer than the upper ones (fig. 92). The branching of this type is also called **monopodial** because there is a single continuous axis, as in beef-wood tree (*Casuarina;* B. & H. JHAU), mast tree (*Polyalthia* ; B. DEBDARU ; H. DEVADARU or ASHOK), etc. As a result of this branching the plant takes on a *conical* or pyramidal shape.

II. Cymose Type. Here the growth of the main stem is definite, that is, the terminal bud does not continue to grow,



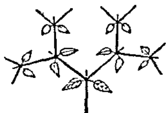






FIG. 92 FIG. 93 FIG. 94 FIG. 95
Types of Branching. Fig. 92. Racemose type. Fig. 93. True (biparous) cyme. Fig. 94. Scorpioid cyme. Fig. 95. Helicoid cyme.

but lower down, the main stem produces one or more lateral

branches which grow more vigorously than the terminal one. The process may be repeated over and over again. As a result of cymose branching the plant spreads out above, and becomes more or less dome-shaped. Cymose branching may be of the following kinds:

1. **Uniparous Cyme.** If, in the cymose type, only one lateral branch is produced at a time, the branching is said to be uniparous or monochasial. The uniparous type of branching is otherwise called **sympodial** (*syn*, together or united; *podos*, foot) because there is a succession of daughter axes (false axes) fused together in course of development of the plant (figs. 96-7). It has two distinct forms: (*a*) **helicoid** or one-sided cyme (fig. 95), when successive lateral branches develop on the same side, forming a sort of helix, as in *Saraca* (B. ASOK; H. SEETA ASHOK), and (*b*) **scorpioid** or alternate-sided cyme (fig. 94), when successive lateral branches develop on alternate sides, forming a zig-zag, as in vine (*Vitis vinifera*), *Cissus quadrangularis* (B. & H. HARHJORA), *Vitis trifolia* (B. AMAL-LATA; H. AMALBEL), etc. In them the apparent or false axis (**sympodium**) is a succession of lateral axes, and the tendrils are modified terminal vegetative buds (figs. 96-7).

2. **Biparous Cyme.** If, in the cymose branching, two lateral axes develop at a time, it is called biparous or dichasial (fig. 93). Examples are seen in mistletoe (see fig. 69), *Ervatamia*

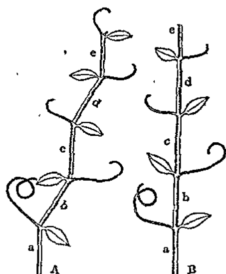


Fig. 96

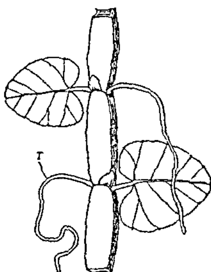


Fig. 97

Sympodial Branching. Fig. 96. *A*, scorpioid type showing terminal tendrils and lateral axes; *B*, the same straightened out after growth; *a-e* are respective axes of sympodium. Fig. 97. Sympodial branching of *Cissus quadrangularis* (B. & H. HARHJORA); *T*, a tendril.

(= *Tabernaemontana* ; B. TAGAR ; H. CHANDNI), four o'clock plant (*Mirabilis* ; B. KRISHNAKOLI ; H. GUL-ABBAS), *Carissa* (B. KARANJA ; H. KARONDA), pagoda tree (*Plumeria* ; B. KAT-CHAMPA ; H. GOLAINCHI) and *Stellaria media.* Sometimes it so happens that the terminal bud remains undeveloped or soon dies off, the branching then looks like a dichotomy, often called *false dichotomy.*

3. **Multiparous Cyme.** If more than two branches develop at a time, the branching is said to be multiparous or polychasial, as in *Croton sparsiflorus* and some species of *Euphorbia.*

B. Dichotomous Branching. When the terminal bud bifurcates, that is, divides into two, producing two branches in a forked manner, the branching is termed **dichotomous.** Dichotomous branching is common among the 'flowerless' plants. It may be of the following kinds:

1. **True Dichotomy.** When the terminal bud divides into two, forming two equally strong axes which in their turn may branch again in the same manner, the branching is called **true dichotomy.** Dichotomous branching is commonly found in cryptogams, as in *Riccia*, *Marchantia*, *Lycopodium phlegmaria* (an epiphytic *Lycopodium* ; see fig. 675), etc. Among the 'flowering' plants examples are afforded by

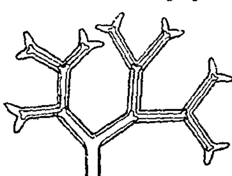


FIG. 98



FIG. 99

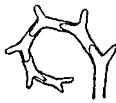


FIG. 100

Types of Branching (*contd.*). Fig. 98. True dichotomy. Fig. 99. Scorpioid dichotomy. Fig. 100. Helicoid dichotomy.

Hyphaene (a kind of palm), screwpine (*Pandanus* ; B. KETUCKY; H. & P. KEORA), *Canscora* (a weed), etc.

2. **Sympodial Dichotomy.** When the dichotomous branches are suppressed successively on the same side or on alternate sides, the branching is known as **sympodial dichotomy.** As in the sympodial cyme, this has also got two forms: (1) **helicoid dichotomy** and (2) **scorpioid dichotomy.** In the

former the suppression of one arm of the forked branches takes place always on the same side, and in the latter the suppression takes place on alternate sides.

Functions of the Stem

1. **Conduction.** It *conducts* water and dissolved mineral salts from the root to the leaf, and prepared food material from the leaf to the different parts of the plant body, particularly to the storage organs and the growing regions.

2. **Support.** The main stem acts as a sort of pillar *supporting* the branches which often spread out in different directions.

3. **Bearing leaves, etc.** The stem and the branches *bear* leaves and distribute them out on all sides so that all of them may get the maximum amount of sunlight for manufacture of food material. They also bear flowers for reproduction of the plant.

4. **Storage.** The stem also serves as a *storehouse* of food material. This is particularly true of the underground modified stems (see figs. 73-7) which are specially constructed for food storage, as in ginger, potato, onion and *Amorphophallus* (B. OL ; H. KANDA). Fleshy stems of cacti and spurges (*Euphorbia*) always store a large quantity of water.

5. **Food Manufacture.** The young shoot, when green in colour, *manufactures* food material in the presence of sunlight with the help of chloroplasts contained in it.

In addition to those stated above, metamorphosed stems (see pp. 53-7) carry on specialized functions; for example, the tendril helps a plant to climb, and the thorn protects it against grazing animals.

CHAPTER V

THE LEAF

The leaf may be regarded as the flattened, lateral outgrowth of the stem or the branch, developing from a node and having a bud in its axil. It is normally green in colour and is regarded as the most important vegetative organ of the plant since food material is prepared in it. Leaves always follow an *acropetal* order of development and are *exogenous* in origin.

(= *Tabernaemontana* ; B. TAGAR ; H. CHANDNI), four o'clock plant (*Mirabilis* ; B. KRISHNAKOLI ; H. GUL-ABBAS), *Carissa* (B. KARANJA ; H. KARONDA), pagoda tree (*Plumeria* ; B. KAT-CHAMPA ; H. GOLAINCHI) and *Stellaria media*. Sometimes it so happens that the terminal bud remains undeveloped or soon dies off, the branching then looks like a dichotomy, often called *false dichotomy*.

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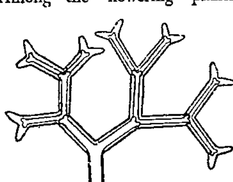






FIG. 98 FIG. 99 FIG. 100

Types of Branching (*contd.*). Fig. 98. True dichotomy. Fig. 99. Scorpioid dichotomy. Fig. 100. Helicoid dichotomy.

Hyphaene (a kind of palm), screwpine (*Pandanus* ; B. KETUCKY; H. & P. KEORA), *Canscora* (a weed), etc.

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CHAPTER V

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Parts of a Leaf (fig. 101)

A typical leaf consists of the following parts:

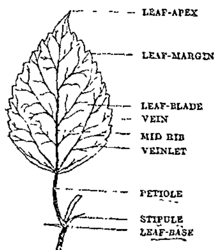


FIG. 101 Parts of a leaf.

1. **Leaf-base** is the part attached to the stem. In many plants the leaf-base expands into a **sheath** which partially or wholly clasps the stem. This *sheathing* leaf-base is of frequent occurrence among monocotyledons, and is well developed in grasses; in the banana plant the so-called stem is made up of leaf-sheaths. In dicotyledons, on the other hand, the leaf-base usually bears two lateral outgrowths, known as the **stipules.** In some leaves such as those of gram, pea, tamarind, sensitive plant, rain tree, gold mohur, butterfly pea (*Clitoria*), etc., the leaf-base is swollen, and then it is known as the **pulvinus.**

2. **Petiole** is the stalk of the leaf. A long petiole pushes out the leaf-blade and thus helps it to secure more sunlight. When the petiole is absent the leaf is said to be **sessile;** and when present it is said to be **petiolate** or stalked. Commonly the petiole is a cylindrical structure being terete, i.e. more or less circular in cross section, or grooved, i.e. provided with a

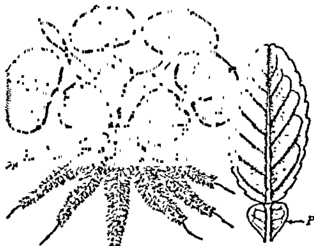


FIG. 102 FIG. 103

Fig. 102. Water hyacinth leaf with bulbous petiole
Fig. 103. Pummelo leaf with winged petiole (*P*).

longitudinal furrow. But in many cases the petiole shows certain peculiarities. Thus in water hyacinth (fig. 102) it swells into a spongy bulb, often called pseudo-bulb, containing innumerable air-chambers for facility of floating, while in orange, pummelo, etc., it becomes winged (fig. 103). In Australian *Acacia* (see fig. 151) it is modified into a flattened sickle-shaped lamina or blade, called phyllode. In *Clematis* (see fig. 62) the petiole is tendrillar in nature.

The **petiole** of the leaf may be described as follows: it may be **filiform**, i.e. long and slender; **terete**, i.e. cylindrical being circular in cross-section; **striate**, i.e. marked with longitudinal lines or furrows; **grooved**, i.e. provided with a long furrow; **flattened**; or **angled**.

3. **Leaf-blade** or **lamina** is the green, expanded portion. The leaf-blade may be studied with reference to the following characters: the nature of the apex and the margin, the surface of the leaf, the general shape of the leaf, the distribution of veins, the nature of the leaf as a whole—simple or compound, and any modification of it. A strong vein, known as the **mid-rib**, runs centrally through the leaf-blade from its base to the apex; this produces thinner lateral **veins** which in their turn give rise to still thinner veins or veinlets. The lamina is the most important part of the leaf since this is the seat of food-manufacture for the entire plant. *Its external and internal organization is well-adapted for this purpose as well as for other functions it has to carry on* (see pp. 88-90).

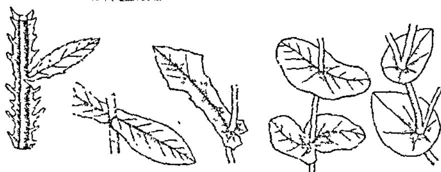


FIG. 104 FIG. 105 FIG. 106 FIG. 107 FIG. 108

Sessile Leaves. Fig. 104. Decurrent leaf of *Laggera pterodonta*. Fig. 105. Auriculate leaves of madar (*Calotropis*). Fig. 106. Amplexicaul leaf of *Emilia sonchifolia*. Fig. 107. Connate leaves of *Lonicera flava*. Fig. 108. Perfoliate leaves.

When the lobes at the base of the leaf partially enclose the stem, the leaf is said to be **auriculate** (*auricle*, lobe), as in madar (*Calotropis*), *Sonchus*, etc.; when completely, it is called **amplexicaul** (*amplexus*, embrace; *caulis*, stem), as in grass, wheat and cauline leaves of *Emilia*; when incompletely, it is called **semi-amplexicaul**, as in buttercup, palms, etc.; when the lobes meet across the stem and fuse together so that the latter seems to pass through the leaf-blade, the leaf is said to be **perfoliate** (*per*, through; *folium*,

a leaf), as in *Canscora perfoliata*, *Aloe perfoliata*, etc. When two sessile opposite leaves meet each other across the stem and fuse together, they are said to be **connate**, as in *Canscora diffusa* (B. DANKUNI) and wild honeysuckle (*Lonicera flava*) In some cases, as in *Laggera pterodonta*, *Laggera alata*, *Canscora decurrens*, *Crotalaria alata* and some of the thistles, the petiole and the leaf-base become winged, and this wing extends down the stem so that the latter also seems to be winged; a leaf of this nature is said to be **decurrent.**

Kinds of Leaves. **1. Foliage Leaves.** These are ordinary green leaves borne by the stem or the branch. **2. Seed Leaves or Cotyledons.** These are leaves attached to the axis of embryo of the seed. They may be fleshy, as in gram, pea, etc., or thin and flat, as in castor seed. **3. Scale Leaves.** These are small, dry (sometimes fleshy, as in onion), stalkless, usually brownish structures (see p 80) Their function is to protect the bud in their axil. **4. Bract Leaves or Bracts.** These are special leaves, green or coloured, bearing a single flower or a cluster of flowers in their axil. **5. Floral Leaves.** The different members of a flower such as sepals, petals, stamens and carpels are regarded as highly specialized leaves meant essentially for the reproduction of the plant. **6. Sporophylls.** These are leaves bearing spores for asexual reproduction, as in ferns.

STIPULES

Stipules are the lateral appendages of the leaf borne at its base. These are often green, but sometimes they have a withered look. They may remain as long as the lamina persists **(persistent)** or may fall off soon after the lamina unfolds **(deciduous)**, or sometimes they may shed even before the lamina unfolds **(caducous).** Their function is to protect the

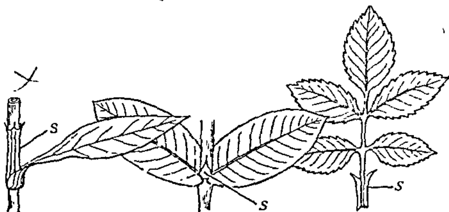


FIG. 109 FIG. 110 FIG. 111

Kinds of Stipules. Fig. 109. Ochreate stipule (s) of *Polygonum*. Fig. 110. Interpetiolar stipule (s) of *Ixora*. Fig. 111. Adnate stipule (s) of rose.

young leaves in the bud, and when green they carry on the manufacture of food material like leaves. When stipules are present the leaf is said to be **stipulate**, and when absent **exstipulate.** Sometimes, as in butterfly pea (*Clitoria*; B. APARA-

JITA; H. APARAJIT), a small stipule is present at the base of each leaflet. Such a small stipule is otherwise known as a *stipel*.

Kinds of Stipules. According to their shape, position, colour and size, the stipules are of the following kinds.

1. **Free Lateral Stipules** (fig. 101). These are two free stipules, usually small and green in colour, borne on the two sides of the leaf-base, as in China rose, cotton, etc.

2. **Scaly Stipules.** These are small dry scales, usually two in number, borne on the two sides of the leaf-base, as in *Desmodium*, e.g. Indian telegraph plant (*Desmodium gyrans*; B. BAN-CHANDAL; H. BAN-CHAL) and *D. gangeticum*.

3. **Adnate Stipules** (fig. 111). These are the two lateral stipules that grow along the petiole up to a certain height, adhering to it and making it somewhat winged in appearance, as in rose, ground nut (B. CHINA-BADAM; H. MUNGPHALI), strawberry and lupin.

4. **Interpetiolar Stipules** (fig. 110). These are the two stipules that lie between the petioles of opposite or whorled leaves, thus alternating with the latter. These are seen in *Ixora* (B. RANGAN; H. GOTAGANDHAL), *Anthocephalus* (B. & H. KADAM), *Vangueria* (B. MOYENA; H. MOINA), etc.

5. **Ochreate Stipules** (fig. 109). They form a hollow tube encircling the stem from the node up to a certain height of the internode in front of the petiole, as in *Polygonum* (B. PANI-MARICH; P. NARRI), sorrel (*Rumex*; B. CHUKA-PALANG; H. KHATTA-PALAK; P. KHATTA-MITHA), etc.

6. **Foliaceous Stipules** (see figs. 144-5). These are two large, green, leafy structures, as in pea (*Pisum*), wild pea (*Lathyrus*) and some varieties of passion-flower.

7. **Bud-scales.** These are scaly stipules which enclose and protect the vegetative buds, and fall off as soon as the leaves unfold. They are seen in banyan, jack, *Magnolia*, iron-wood tree (*Mesua*; B. NAGESWAR; H. NAGKESAR), etc.

Modified Forms of Stipules. Stipules are sometimes modified into spines and tendrils, and perform functions peculiar to these two structures. (1) **Spinous stipules** (fig. 112). In some plants, as in gum tree (*Acacia*), Indian plum (*Zizyphus*), sensitive plant (*Mimosa*), caper (*Capparis*), etc., the stipules become modified into two sharp pointed structures known as spines, one on each side of the leaf-base. Such spinous stipules give protection to the leaf against the attack of herbivorous

animals. (2) **Tendrillar stipules** (fig. 113). In sarsaparilla (*Smilax*; B. KUMARIKA; H. CHOBCHINI) the stipules become



FIG. 112. Spinous stipules of Indian plum (*Zizyphus*).

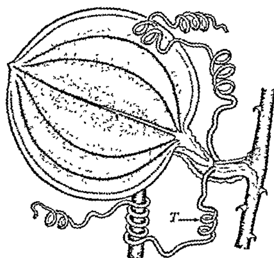


FIG. 113. Tendrillar stipules (*T*) of *Smilax*.

modified into two strong closely-coiled tendrils, one on each side of the petiole. These tendrillar stipules help the plant to climb neighbouring shrubs and trees. Although the tendrils in *Smilax* (a monocotyledon) are commonly regarded as modified stipules, the latter (i.e. stipules) are scarcely found in monocotyledons.

LEAF-BLADE

Apex of the Leaf (fig. 114). The apex of the leaf is said to be (1) **obtuse**, when it is rounded, as in banyan (*Ficus bengalensis*); (2) **acute**, when it is pointed in the form of an acute angle, but not stiff, as in China rose; (3) **acuminate** or **caudate**, when it is drawn out into a long slender tail, as in peepul (*Ficus religiosa*) and lady's umbrella (*Holmskioldia*); (4) **cuspidate**, when it ends in a long rigid sharp (spiny) point, as in date-palm,

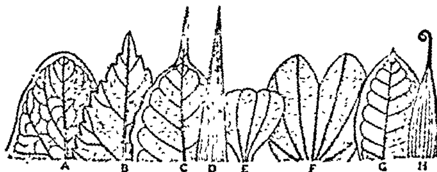


FIG. 114. Apex of the leaf. *A*, obtuse; *B*, acute; *C*, acuminate; *D*, cuspidate; *E*, retuse; *F*, emarginate; *G*, mucronate; and *H*, cirrhose.

screwpine and pineapple; (5) **truncate**, when it ends abruptly as if cut off in a straight line, as in Indian sago palm (*Caryota urens*) and *Bauhinia anguina* (a large climber); (6) **retuse**, when the obtuse or truncate apex is furnished with a shallow notch, as in water lettuce (*Pistia*); (7) **emarginate**, when the apex is provided with a deep notch, as in *Bauhinia* (B. KANCHAN, H. KACHNAR) and wood-sorrel (*Oxalis*); (8) **mucronate**, when the rounded apex abruptly ends in a short point, as in *Ixora* (B. RANGAN; H. GOTAGANDHAL); and (9) **cirrhose** (*cirrus*, a tendril or a curl), when it ends in a tendril, as in glory lily, or in a slender curled thread-like appendage, as in banana.

Margin of the Leaf. The margin of the leaf may be (1) **entire**, i.e. even and smooth, as in mango, jack, banyan, etc.; (2) **repand**, i.e. shallowly wavy or undulating, as in mango; (3) **sinuate**, i.e. deeply undulating, as in mast tree (*Polyalthia*; B. DEBDARU; H. ASHOK) and some garden crotons; (4) **serrate**, i.e. cut like the teeth of a saw and the teeth directed upwards, as in China rose, rose, or margosa (*Melia*; B. & H. NIM or NIMBA); (5) **biserrate**, i.e. doubly serrate (each tooth serrated again); (6) **serrulate**, i.e. minutely serrate; (7) **dentate**, i.e. the teeth directed outwards at right angles to the margin of the leaf, as in melon and water lily; (8) **runcinate**, i.e. serrated with the teeth pointed backwards; (9) **crenate**, i.e. the teeth rounded, as in sprout leaf plant (*Bryophyllum*) and Indian pennywort (*Centella*); (10) **fimbriate**, i.e. fringed with fine segments; (11) **ciliate**, i.e. fringed with hairs; and (12) **spinous**, i.e. provided with spines, as in prickly poppy (*Argemone*).

Surface of the Leaf. The leaf is said to be (1) **glabrous**, when the surface of it is smooth and free from hairs or outgrowths of any kind; (2) **rough**, when the surface is somewhat harsh to touch; (3) **glutinous**, when the surface of it is covered with a sticky exudation, as in tobacco; (4) **glaucous**, when the surface is green and shining; (5) **spiny**, when it is provided with spines; and (6) **hairy**, when it is covered, densely or sparsely, with hairs. Hairy surface may be (*a*) **pubescent**, when it is covered with short soft straight hairs; (*b*) **puberulous**, i.e. minutely pubescent just perceptible to touch; (*c*) **pilose**, i.e. thinly covered with long soft hairs; (*d*) **villous**, i.e. thickly covered with long soft hairs; (*e*) **tomentose**, i.e. densely covered with short soft, more or less tangled hairs; (*f*) **woolly**, i.e. densely covered with soft long curled hairs looking like wool; (*g*) **floccose**, i.e. woolly with locks of hairs easily detachable; (*h*) **hispid**, i.e. beset with rigid or bristly hairs; (*i*) **hirsute**, i.e. covered with long coarse stiff hairs; (*j*) **strigose**, i.e. covered with sharp pointed straight hairs lying along the surface; (*k*) **mealy**, i.e. covered with very minute hairs which may be rubbed off like powder; and (*l*) **pruinose**, i.e. covered with whitish waxy bloom or powder.

Texture of the Leaf. The leaf is said to be (1) **coriaceous**, when it is tough and thick like leather; and sub-coriaceous, when it is thinner and more pliable; (2) **membranous**, when it is thin and pliable like a membrane; (3) **scarious**, when it is thin, dry and non-green; (4) **fleshy**, when thick and soft; and (5) **succulent**, when fleshy and juicy.

VENATION

Veins [illegible] from the petiole and [illegible] different directions; [illegible]le of conducting and mechanical tissues—the former serving to distribute the water and dissolved mineral salts throughout the lamina and to carry away the prepared food from it, while the latter to give necessary amount of strength and rigidity to the thin, flat leaf-lamina.

The arrangement of the veins and the veinlets in the leaf-blade is known as **venation.** There are two principal types of venation, viz. **reticulate,** when the veinlets are irregularly distributed, forming a network; and **parallel,** when they run parallel to each other. The former is characteristic of dicotyledons and the latter of monocotyledons.

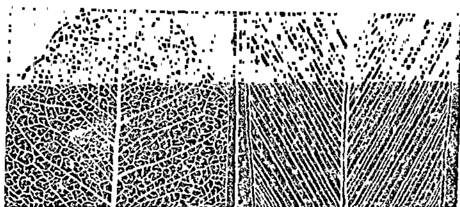


FIG. 115 FIG 116

Systems of Veins. Fig 115. Reticulate venation in a dicotyledonous leaf. Fig. 116. Parallel venation in a monocotyledonous leaf.

Exceptions: Among monocotyledons sarsaparilla (*Smilax*; B. KUMARIKA; H. CHOBCHINI—fig. 118), aroids, and yams (*Dioscorea*), e.g. white yam (*Dioscorea alata*; B. & H. CHUPRI-ALOO —fig. 117), etc., show reticulate venation and among dicoty-

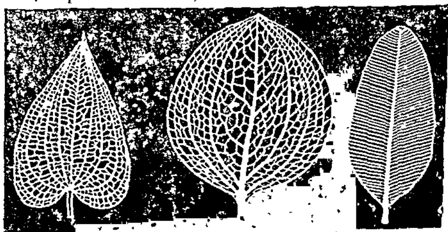


FIG. 117 FIG. 118 FIG. 119

Fig. 117. Leaf of *Dioscorea* (a monocotyledon) showing reticulate venation.
Fig. 118. Leaf of *Smilax* (a monocotyledon) showing reticulate venation.
Fig. 119. Leaf of *Calophyllum* (a dicotyledon) showing parallel venation.

ledons Alexandrian laurel (*Calophyllum* ; B. & H. SULTANA-CHAMPA—fig. 119) and a few others show parallel venation.

I. Reticulate Venation

1. **Pinnate or Unicostate Type** (*unus*, one ; *costa*, a rib) In this type of venation there is a strong mid-rib or costa ; this



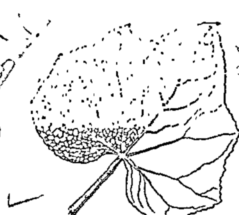




FIG. 120 FIG. 121 FIG. 122

Types of Reticulate Venation. Fig. 120. Peepul leaf showing pinnate type. Fig. 121. Cucumber leaf showing palmate (divergent) type Fig. 122. Bay leaf showing palmate (convergent) type.

gives off lateral veins which proceed towards the margin or apex of the leaf, like plumes in a feather (fig. 120). These are then connected by smaller veins which pass in all directions, forming :

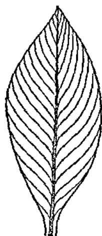
2. [illegible] ,
type there [illegible]
arise from the tip of the petiole and proceed outwards or upwards. There are two forms: (1) in one the leaf possesses a number of strong veins or costa that arise at the base of the leaf-blade and then diverge from one another towards the margin of the leaf, like the fingers from the palm (**divergent type** ; fig. 121) ; these are then connected by a network of smaller veins, as in papaw, cucumber, castor, China rose, etc. ; and (2) in the other the veins, instead of diverging from one another, run in a curved manner from the base of the blade [illegible] 122), as in cinnamon, camphor, [illegible] 3), bay leaf (B. TEZPATA ; H. [illegible] ; H. KUCHLA), etc. The leaf in this case is said to be curve-veined.

II. Parallel Venation

1. **Pinnate or Unicostate Type** (fig. 123). In this type of venation the leaf has a prominent mid-rib, and this gives off

lateral veins which proceed parallel to each other towards the margin or apex of the leaf-blade, as in plantain, ginger, *Canna*, turmeric, etc.

2. **Palmate Type.** Two forms are also met with here:





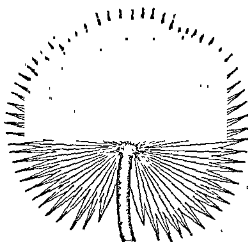
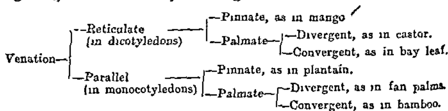


FIG. 123 FIG. 124 FIG. 125

Types of Parallel Venation Fig. 123. Pinnate type in *Canna* leaf. Fig. 124. Palmate (convergent) type in bamboo leaf. Fig. 125 Palmate (divergent) type in palmyra-palm leaf.

(1) the veins arise from the tip of the petiole and proceed (diverge) towards the margin of the leaf-blade in a more or less parallel manner (**divergent type**; fig. 125), as in fan palms such as palmyra-palm; and (2) a number of more or less equally strong veins proceed from the base of the leaf-blade to its apex in a somewhat parallel direction (**convergent type**; fig. 124), as in water hyacinth, grasses, rice, bamboo, etc.



Functions of Veins

1. Veins form the skeleton of the leaf-blade and give rigidity to it so that it does not get torn or crumpled when a strong wind blows.

2. Veins help the leaf-blade to keep flat so that it may be evenly illuminated by the sunlight.

3. Veins distribute water and mineral salts received from the stem throughout the leaf-blade, collect the prepared

food material from the blade and send it to the stem, and thence to the storage organs and the growing regions.

SHAPE OF THE LEAF

A. **Linear,** when the leaf is long and narrow, as in many grasses.

B. **Lanceolate,** when the shape of the leaf is like that of a lance, as in bamboo, oleander (*Nerium*), etc.

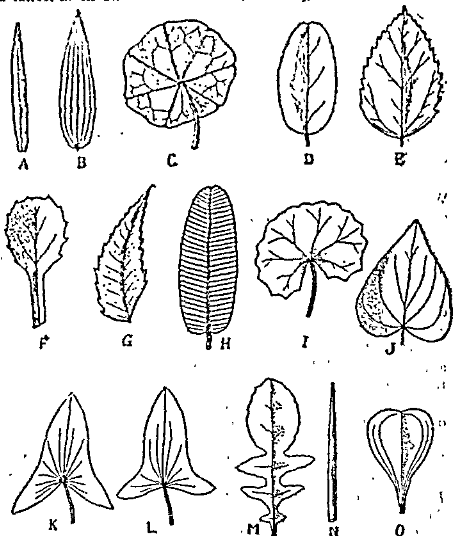


Fig. 126. Shape of the leaf. *A*, linear; *B*, lanceolate; *C*, rotund; *D*, elliptical or oval; *E*, ovate or egg-shaped; *F*, spathulate; *G*, oblique; *H*, oblong; *I*, reniform; *J*, cordate; *K*, sagittate; *L*, hastate; *M*, lyrate; *N*, acicular or needle-shaped; and *O*, cuneate or wedge-shaped.

C. **Rotund or orbicular,** when the blade is circular in outline, as in lotus, garden nasturtium, etc.

D. **Elliptical or oval,** when the leaf has more or less the shape of an ellipse, as in rose-apple, guava, jack, etc.

E. **Ovate,** when the blade is egg-shaped, i.e. slightly broader at the base than at the apex, as in banyan and China rose When the leaf is inversely egg-shaped it is said to be *obovate*, as in country almond.

F. **Spathulate,** when the shape is like that of a spatula, that is, broad and round at the top and narrower towards the base, as in *Calendula* and sundew (*Drosera*).

G. **Oblique,** when the two halves of a leaf are unequal, as in *Begonia*. In margosa (B. & H. NIM), Indian cork tree (B. AKAS-NIM), etc., the leaflets are oblique.

H. **Oblong,** when the blade is wide and long, with the two margins running more or less straight up, as in banana.

I. **Reniform,** when it is kidney-shaped, as in Indian pennywort (B. THULKURI ; H. BRAHMA-MANDUKI ; P. BRAHMI-BOOTI).

J. **Cordate,** when the blade is heart-shaped, as in betel. When the leaf is inversely heart-shaped it is said to be *obcordate*, as in wood-sorrel (*Oxalis* ; B. AMRUL-SAK ; H. CHUKA-TRIPATI).

K. **Sagittate,** when the blade is shaped like an arrow, as in arrowhead and some aroids.

L. **Hastate,** when the two lobes of a sagittate leaf are directed outwards, as in water bindweed (*Ipomoea* ; B. KALMI-SAK) and *Typhonium* (B. GHET-KACHU).

M. **Lyrate,** when the shape is like that of a lyre, i.e. with a large terminal lobe and some smaller lateral lobes, as in radish, mustard, etc.

N. **Acicular,** when the leaf is long, narrow and cylindrical, i.e. needle-shaped, as in pine.

O. **Cuneate,** when the leaf is wedge-shaped, as in water lettuce (*Pistia* ; B. PANA ; H. JAL-KHUMBI).

P. **Falcate,** when the leaf is sickle-shaped, as in *Eucalyptus globulus* and *Arundinaria falcata* (a bamboo). In Australian *Acacia* the phyllode is falcate.

Incision of the Leaf-blade. In the pinnately veined leaf the incision or cutting of the leaf-blade proceeds from the margin towards the mid-rib (pinnate type), and in the palmately veined leaf it passes towards the base of the leaf-blade (palmate type).

First Series: **Pinnate Type.** (1) **Pinnatifid,** when the incision of the margin is half-way or nearly half-way down towards the mid-rib, as in poppy. (2) **Pinnatipartite,** when the incision is more than half-way down towards the mid rib, as in radish, mustard, etc. (3) **Pinnatisect,** when the incision is carried down to near the mid rib, as in some ferns. *Quamoclit* (B. KUNJALATA

OF TORULATA; H. KAMALATA), *Cosmos*, etc





FIG. 127 FIG. 128
Fig. 127. Lyrate leaf of radish. Fig. 128. Pedate leaf of *Vitis pedata*.

(4) **Pinnate compound** (see figs 134-7), when the incision of the margin reaches the mid-rib, thus dividing the leaf into a number of segments or leaflets, as in pea, gram, etc.
Second Series **Palmate Type.** (1) **Palmatifid,** as in passion-flower, cotton, etc (2) **Palmatipartite,** as in castor, papaw, etc. (3) **Palmatisect,** as in tapioca, hemp (*Cannabis*; B. & H. GANJA) and some aroids, e.g., snake plant (see fig 183). (4) **Palmate compound** (see figs. 139-40), when the incision is carried down to the base of the leaf-blade, as in silk cotton tree.

In the pinnate type, when the lobes of a leaf are of unequal sizes, the terminal one being larger than the lateral ones, which again become gradually smaller towards the base, the leaf is said to be **lyrate** (fig. 127), as in mustard, radish, etc. In the palmate type, when the leaf is divided into a number of lobes which spread in the manner of the claw of a bird, remaining connected at the base only, the leaf is said to be **pedate** (fig. 128), as in *Vitis pedata* (B. GOALE LATA).

COMPOUND LEAVES : PINNATE AND PALMATE

Simple Leaf and Compound Leaf. A leaf is said to be simple when it consists of a single blade which may be entire or incised (and, therefore, lobed) to any depth, but not down to



FIG. 129 FIG. 130 FIG. 131 FIG. 132
Fig 129. A simple leaf. Fig. 130. A branch. Fig. 131. A pinnately compound leaf with the leaflets articulated to the mid-rib. Fig. 132. A palmately compound leaf with the leaflets articulated to the petiole. Note the position of the bud in each case.

the mid-rib or the petiole; and a leaf is said to be compound when the incision of the leaf-blade goes down to the mid-rib

D. **Elliptical or oval**, when the leaf has more or less the shape of an ellipse, as in rose-apple, guava, jack, etc.

E. **Ovate**, when the blade is egg-shaped, i.e. slightly broader at the base than at the apex, as in banyan and China rose. When the leaf is inversely egg-shaped it is said to be *obovate*, as in country almond.

F. **Spathulate**, when the shape is like that of a spatula, that is, broad and round at the top and narrower towards the base, as in *Calendula* and sundew (*Drosera*).

G. **Oblique**, when the two halves of a leaf are unequal, as in *Begonia*. In margosa (B. & H. NIM), Indian cork tree (B. AKAS-NIM), etc., the leaflets are oblique.

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or TORULATA; H. KAMALATA), *Cosmos*, etc





Fig. 127 Fig. 128
Fig. 127. Lyrate leaf of radish. Fig. 128. Pedate leaf of *Vitis pedata.*

(4) **Pinnate compound** (see figs. 134 7), when the incision of the margin reaches the mid-rib, thus dividing the leaf into a number of segments or leaflets, as in pea, gram, etc

Second Series **Palmate Type.** (1) **Palmatifid,** as in passion-flower, cotton, etc (2) **Palmatipartite,** as in castor, papaw, etc. (3) **Palmatisect,** as in tapioca, hemp (*Cannabis*; B & H. GANJA) and some aroids, e.g., snake plant (see fig 183). (4) **Palmate compound** (see figs. 139-40), when the incision is carried down to the base of the leaf-blade, as in silk cotton tree

In the pinnate type, when the lobes of a leaf are of unequal sizes, the terminal one being larger than the lateral ones, which again become gradually smaller towards the base, the leaf is said to be **lyrate** (fig. 127), as in mustard, radish, etc. In the palmate type, when the leaf is divided into a number of lobes which spread in the manner of the claw of a bird, remaining connected at the base only, the leaf is said to be **pedate** (fig. 128), as in *Vitis pedata* (B. COALE-LATA).

COMPOUND LEAVES : PINNATE AND PALMATE

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Fig. 129 Fig. 130 Fig. 131 Fig. 132
Fig 129. A simple leaf. Fig. 130. A branch. Fig. 131. A pinnately compound leaf with the leaflets articulated to the mid-rib Fig. 132. A palmately compound leaf with the leaflets articulated to the petiole. Note the position of the bud in each case.

the mid-rib or the petiole; and a leaf is said to be **compound** when the incision of the leaf-blade goes down to the mid-rib

(rachis) or to the petiole so that the leaf is broken up into a number of segments, called leaflets, these being free from one another, that is, not connected by any lamina, and more or less distinctly jointed (articulated) at their base. A bud (axillary bud) is present in the axil of a simple or a compound leaf, but it is never present in the axil of the leaflet of a compound leaf. There are two types of compound leaves, viz. **pinnate** and **palmate.**

Compound Leaf and Branch. A compound leaf may be distinguished from a branch by the following facts: (*1*) a compound leaf never bears a terminal bud; whereas a branch always does so; (2) a compound leaf, like a simple one, always bears a bud (axillary bud) in its axil, but itself does not arise in the axil of another leaf; whereas a branch does not bear an axillary bud, but itself occupies the axillary position of a leaf—simple or compound—developing directly from the said bud; (3) the leaflets of a compound leaf have no axillary buds; whereas the leaves (simple) borne on a branch have a bud in their axil; and (4) a branch is always provided with nodes and internodes; while the rachis of a compound leaf is free from them.

I. Pinnately Compound Leaf. A pinnately compound leaf is defined as the one in which the mid-rib, known as the **rachis,** bears *laterally* a number of leaflets, arranged alternately or in an opposite manner, as in tamarind, gram, gold mohur, rain tree, sensitive plant, gum tree (*Acacia*), *Cassia* (B. KALKASUNDE; H. KASONDI), etc. It may be of the following types:

1. **Unipinnate.** When the mid-rib of the pinnately compound leaf bears the leaflets directly, it is said to be unipinnate, as in rose, margosa (B. & H. NIM or NIMBA), etc. When the leaflets are even in number the leaf is said to be **paripinnate** (fig. 134), as in tamarind, gold mohur, sensitive plant, *Cassia*, etc., and when the leaflets are odd in number the leaf is said to be **imparipinnate** (fig. 135), as in rose, margosa (B. & H. NIM or NIMBA), Chinese box (*Murraya*; B. KAMINI; H. MARCHULA; P. MARUA), butterfly pea (*Clitoria*; B. APARAJITA; H. APARAJIT), etc.



FIG. 133. Bifoliate leaf of *Prinsepia*.

The pinnate leaf is said to be unifoliate, when it consists of only one leaflet, as in *Desmodium gangeticum* (B. SALPANI; H. SALPAN; P. SHALPURNI); bifoliate

or unijugate (one pair), when of two leaflets, as in *Balanites* (B. HINGON ; H. HINGOL) and *Prinsepia* (H. & P. BHEKAL—fig. 133) and sometimes in rose ; trifoliate or ternate, when of three leaflets, as in bean, coral tree and *Vitis trifolia* (B. AMAL-LATA ; H. & P. AMALBEL). It may similarly be quadrifoliate, pentafoliate or multifoliate, according as the leaflets are four, five or more in number.

Leaflets also may vary in number in the same plant. Thus in Indian telegraph plant the number varies from one to three; in rose from one to seven; and in sprout leaf plant from one to five.

2. **Bipinnate** (fig. 136). When the compound leaf is twice pinnate, i.e. the mid-rib produces secondary axes which

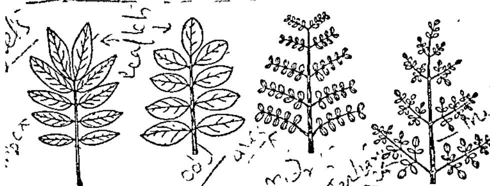


Fig. 134 Fig. 135 Fig. 136 Fig. 137

Pinnate Leaves. Fig. 134. Unipinnate (paripinnate). Fig. 135. Unipinnate (imparipinnate). Fig. 136. Bipinnate. Fig. 137. Tripinnate.

bear the leaflets, it is said to be bipinnate, as in dwarf gold mohur (B. RADHACHURA), gum tree (*Acacia* ; B. BABLA ; H. BABUL ; P. KIKAR), sensitive plant (*Mimosa* ; B. LAJJABATI-LATA ; H. & P. LAJWANTI), Persian lilac (B. GHORA-NIM ; P. BUKAIN), Indian cork tree (B. & H. AKAS-NIM), *Albizzia* (B. & H. SIRISH).

3. **Tripinnate** (fig. 137). When the leaf is thrice pinnate,

SAJINA ; H. SAINJNA : P. SAONJNA) and *Oroxylon* (B. SONA ; H. ARLU ; P. SANNA).

4. **Decompound** (fig. 138). When the leaf is more than thrice pinnate, it is said to be decompound, as in anise, carrot, coriander, *Cosmos*, *Thalictrum foliolosum*, etc.

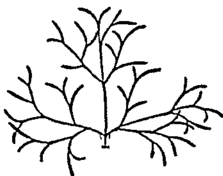


Fig. 138. Decompound leaf of coriander.

caducous; if it lasts one season, usually falling off in winter, it is (2) deciduous or annual; and if it persists for more than one

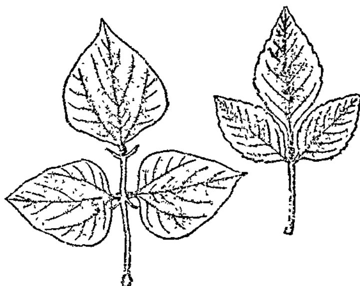


FIG. 142 FIG. 143

Trifoliate Leaves. Fig. 142. Pinnately trifoliate leaf Fig. 143. Palmately trifoliate leaf.

season, usually lasting a number of years, it is (3) persistent or evergreen.

Some Descriptive Terms. (1) **Peltate Leaf.** The leaf-blade and the petiole usually stand in one and the same plane; in some cases, however, as in lotus, water lily, garden nasturtium, etc., the petiole is attached to the centre of the blade at a right angle to it; such a leaf is said to peltate. (2) **Dorsiventral Leaf.** When the leaf is flat, with the blade placed horizontally, showing distinct upper surface and lower surface, it is said to be dorsiventral (*dorsum*, back; *venter*, belly or front). A dorsiventral leaf is more strongly illuminated on the upper surface than on the lower and, therefore, this surface is deeper green in colour than the lower. In internal structure also there is a good deal of difference between the two sides (see fig. 448). (3) **Isobilateral Leaf.** When the leaf is directed vertically upwards, as in many monocotyledons, it is said to be isobilateral (*isos*, equal; *bi*, two; *late*

(4) **Centric Leaf.**
d directed upwards
f is said to be cen-
d, therefore, evenly

green on all sides. (5) **Cauline Leaf.** Commonly leaves are directly borne by the aerial part of the stem and the branches; such leaves are said to be cauline (*caulis*, a stem). (6) **Radical Leaf.** In some cases, as in pine-apple, Indian aloe (B. GHRITA-KUMARI ; H. GHIKAVAR), century plant or American aloe, many lilies, tuberose (B. RAJANI-GANDHA ; H. & P. GULSHABO), etc., a cluster of leaves arises from the short underground stem, as if from the root; such leaves are said to be radical (*radix*, a root). Radical leaves are rather common among monocotyledons. Both radical and cauline leaves may be borne by the same plant, as seen in mustard, radish, etc.

MODIFICATIONS OF LEAVES

Leaves of many plants are modified or metamorphosed into various structures, and carry on specialized functions. These are as follows:

1. **Leaf-tendrils** (figs. 144-47). In some plants leaves are modified into slender, wiry, often closely coiled structures, known as **tendrils.** Tendrils are always climbing organs and are sensitive to contact with a foreign body. Therefore, whenever they come in contact with a neighbouring object they coil round it and help the plant to climb. The leaf may be



FIG. 144 FIG. 145 FIG. 146

Modified Leaves: Leaf tendrils. Fig. 144. Leaf of pea with upper leaflets modified into tendrils. Fig. 145. Portion of wild pea (*Lathyrus*) stem. *T*, tendrils; *S*, stipules. Fig. 146. Portion of glory lily (*Gloriosa*) stem with the leaf apex modified into a tendril.

partially or wholly modified. Thus in pea (fig. 144) only the upper leaflets are seen to be modified into tendrils. In traveller's

joy (*Naravelia*; B. CHHAGAL-BATI—fig. 147) and *Bignonia venusta* (an ornamental climber bearing orange-coloured flowers in huge trusses) it is the terminal leaflet that is converted



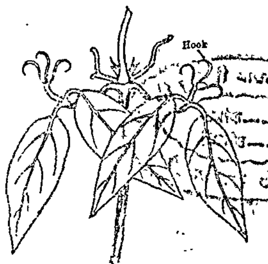


FIG. 147 FIG. 148

Modified Leaves (*contd.*). Fig. 147. Leaf of *Naravelia* with the terminal leaflet modified into a tendril (*t*). Fig. 148. *Bignonia unguis-cati* with hooks.

into a tendril. In glory lily (*Gloriosa*; B. ULAT-CHANDAL; H. KALIARI; P. GURHPATNI—fig. 146) the leaf-apex ends in a closely coiled tendril ... igs. 152-3) the petiole often ... in an upright position. In ... KA; H. CHOB-CHINI) the sti ... fig. 113). The above are cas ... pea (*Lathyrus aphaca*; fig. 145), however, the whole leaf is transformed into a single tendril; while the two foliaceous stipules take over the functions of the leaf.

Hooks. In *Bignonia unguis-cati* (fig. 148), an elegant climber, common in Assam, the terminal leaflets become modified into three, very sharp, stiff and curved hooks, very much like the nails of a cat. These hooks cling to the bark of a tree and act as organs of support for climbing. The plant thus easily climbs to the top of a lofty tree.

2. **Leaf-spines** (figs. 149-50). Leaves of certain plants become modified for defensive purpose into sharp, pointed structures, known as **spines.** That spines are modifications of leaves is evident from the fact that they occupy the same position as the leaves and that they often bear a bud in their axil, as seen in the flowering shoot of barberry (fig. 149). In prickly pear (B. PHANI-MANSHA; H. NAGPHANI; P. NAGPHAN—see fig. 88) ordinary leaves are feebly developed and soon fall off, but the minute leaves of the axillary bud are modified into

4. **Phyllode** (fig. 151). In Australian *Acacia* the petiole or any part of the rachis becomes flattened or winged taking

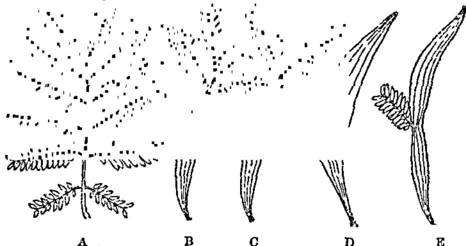


FIG. 151. Development of phyllode in Australian *Acacia*. *A-D*, petiole modified into phyllode; E, rachis and petiole together modified into a phyllode.

the shape of the leaf and turning green in colour. This flattened

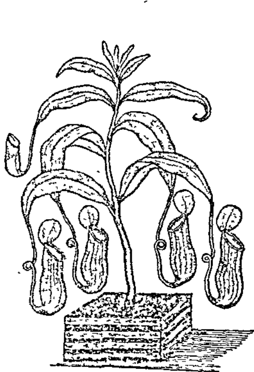


FIG. 152

Fig. 152. Pitcher plant (*Nepenthes*)

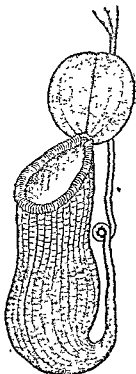


FIG. 153

Fig. 153. A pitcher.

spines. In barberry (fig. 149), on the other hand, the leaf itself becomes modified into a spine; while the leaves of the axillary





Fig. 149 Fig. 150

Modified Leaves (*contd.*). Fig. 149. Barberry. Primary leaves modified into spines (S). Fig. 150. Leaf of prickly poppy (*Argemone*) showing spines.

bud are normal. Spines may also develop at the apex, as in date-palm, dagger plant (see fig. 180), etc., or on the margin,
ANTA; H. PILA-
he places, as in
an aloe (*Agave*).

, dry, stalkless,
colour or some-
he axillary bud
leaves are thick
and fleshy, as in onion; then their function is to store up water and food. Scale-leaves are common on underground stems (see figs. 73-7) where they cover and protect the axillary buds under adverse conditions. These are also common on parasites (see figs. 67-8) and saprophytes (see fig. 72) where they *replace the* green vegetative leaves. In *Ficus* (fig. banyan, peepul, India-rubber plant, etc.) the bud-scales protect the young leaves of the bud. Often in winter-buds the outer leaves (scale-leaves) are thin, dry and membranous. In phylloclades and cladodes (see figs. 88 & 91) leaves are often modified into small, dry scales. In *Equisetum* and *Casuarina* (B. & H. JHAU) the scale-leaves occur in a whorl at each node, while in *Tamarix* (B. & H. BAN-JHAU; P. PILCHI) small, sheathing scale-leaves occur clasping the stem.

4. **Phyllode** (fig. 151). In Australian *Acacia* the petiole or any part of the rachis becomes flattened or winged taking

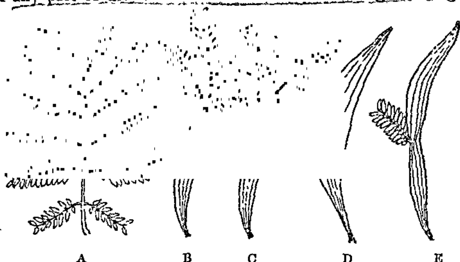


FIG. 151. Development of phyllode in Australian *Acacia*. *A-D*, petiole modified into phyllode; E, rachis and petiole together modified into a phyllode.

the shape of the leaf and turning green in colour. This flattened

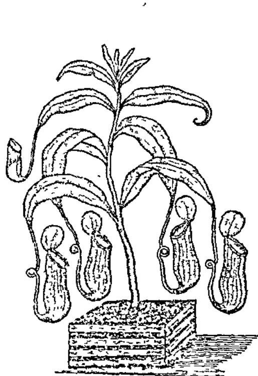


FIG. 152

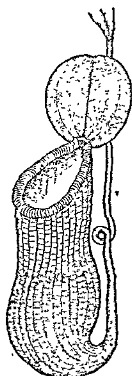


FIG. 153

Fig. 152. Pitcher plant (*Nepenthes*) Fig. 153. A pitcher.

it has an opening—a basal one, but no lid, and instead of the same there is a sort of tongue projecting inwards. A root enters the cavity of the pitcher and becomes much branched. After a shower of rain, water flows down into the pitcher. Prior to this, debris is collected there by ants. All this is then absorbed by the said root.

6. **Bladder** (fig. 155). In bladderwort (*Utricularia*), a floating weed commonly found in tanks, the leaf is very much

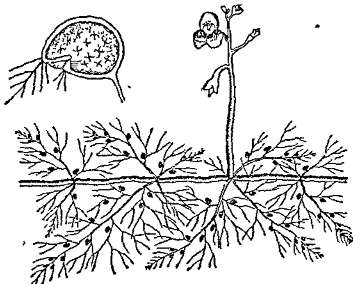


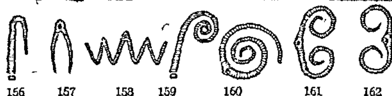
FIG. 155. Bladderwort (*Utricularia*) with many small bladders; *top*, a bladder in section (magnified).

segmented. Some of these segments are modified to form bladder-like structures, with a trap-door entrance which allows aquatic animalcules to pass in, but never to come out.

PREFOLIATION

The way in which leaves are arranged in the bud is known as **prefoliation.** This is considered from two standpoints, viz. *first*, the way in which each individual leaf is rolled or folded in the bud (**ptyxis**); and *second*, the way in which the leaves are arranged in the bud with respect to each other (**vernation**). The arrangement of foliage leaves in the vegetative bud and that of the floral leaves in the flower-bud are nearly the same, and as such the same terms are used to explain the identical types in both cases.

A. **Ptyxis.** Rolling or folding of individual leaves may be as follows:



Ptyxis. FIG. 156. Reclinate. FIG. 157. Conduplicate. FIG. 158. Plicate. FIG. 159. Circinate. FIG. 160. Convolute. FIG. 161. Involute. FIG. 162. Revolute.

1. **Reclinate,** when the upper half of the leaf-blade is bent upon the lower half, as in loquat.

2 *Conduplicate,* when the leaf is folded lengthwise along the mid-rib, as in guava, sweet potato and camel's foot tree (*Bauhinia*; B. KANCHAN; H. KACHNAR).

3 **Plicate** or **plaited,** when the leaf is repeatedly folded longitudinally along ribs in a *zigzag* manner, as in fan- or palmyra-palm.

4. **Circinate,** when the leaf is rolled from the apex towards the base like the tail of a dog, as in ferns

5. **Convolute,** when the leaf is rolled from one margin to the other, as in plantain, aroids and Indian pennywort.

6. **Involute,** when the two margins are rolled on the upper surface of the leaf towards the mid-rib or the centre of the leaf, as in water lily, lotus, Sandwich island climber (*Corculum = Antigonon*) and *Plumbago* (B. CHITA; H. & P. CHITRAK).

7. **Revolute,** when the leaf is similarly rolled on its lower surface, as in oleander and country almond.

8. **Crumpled,** when the leaf is irregularly folded, as in cabbage.



Fig. 163



Fig. 164



Fig. 165



Fig. 166

Vernation. Fig. 163. Valvate. Fig. 164. Twisted. Fig. 165. Imbricate. Fig. 166. Equitant.

B. Vernation. Vernation of leaves, as seen in a transverse section of the bud, may be, as follows :

1. **Valvate,** when the leaves of the bud simply touch one another by their margins but do not overlap.

2. **Twisted** or **contorted,** when the leaves are overlapped by one margin and they overlap the next leaf by the other margin.

3. **Imbricate,** when some leaves overlap others by their margins and some are internal or twisted.

4. **Equitant,** when the leaves overlap the next opposite ones by both the margins, as in *Vanda* (B & H. RASNA), sweet flag (*Acorus calamus*; B. BOCH; H. & P. WACH) and *Belamcanda* (B. DASBAICHANDI).

PHYLLOTAXY

The term **phyllotaxy** (*phylla*, leaves; *taxis*, arrangement) means the various modes in which the leaves are arranged on the stem or the branch. The object of this arrangement is to avoid shading one another so that the leaves may get the maximum amount of sunlight to carry on their function of the manufacture of food. Three principal types of phyllotaxy are noticed in plants.

1. **Alternate or Spiral** (fig. 167), when a single leaf arises at each node, as in tobacco, China rose, mustard, sunflower, etc.

2. **Opposite** (fig. 168), when two leaves arise at each node standing opposite each other. In opposite phyllotaxy one pair of leaves is most commonly seen to stand at a right angle to the next upper or lower pair. Such an arrangement of leaves is said to be opposite decussate or simply **decussate**. This is seen

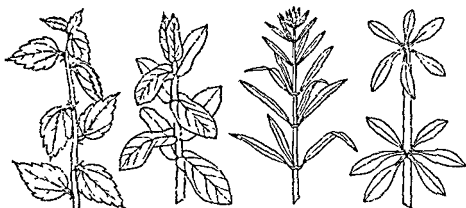


FIG. 167 FIG. 168 FIG. 169 FIG. 170

Types of Phyllotaxy. Fig. 167. Alternate phyllotaxy of China rose. Fig. 168. Opposite phyllotaxy of madar (*Calotropis*). Fig. 169. Whorled phyllotaxy of oleander (*Nerium*). Fig. 170 Ditto of devil tree (*Alstonia*).

in sacred basil (*Ocimum* ; B. & H. TULSI), madar (*Calotropis* ; B. AKANDA ; H. & P. AK), guava, etc. Sometimes, however, a pair of leaves is seen to stand directly over the lower pair in the same plane. Such an arrangement of leaves is said to be **superposed**, as in Rangoon creeper (*Quisqualis*). Branches growing in the horizontal direction, as in guava, *Ixora*, etc., commonly bear superposed leaves. Not infrequently the same plant shows both alternate and opposite phyllotaxes.

3. **Whorled** (figs. 169-70), when there are more than two leaves at each node and these are arranged in a circle or whorl, as in devil tree (*Alstonia* ; B. CHHATIM ; H. CHATIUM), oleander (*Nerium* ; B. KARAVI ; H. & P. KANER), *Allamanda*, *Vangueria* (B. MOYENA ; H. MOINA), etc. Sometimes both opposite and whorled phyllotaxes may be seen in the same plant.

Alternate Phyllotaxy. *The leaves in this case are seen to* be spirally arranged round the stem. Now, if an imaginary spiral line be drawn from the base of one particular leaf,

and this line be passed round the stem through the bases of the successive leaves, it is seen that the spiral line finally reaches a leaf which stands vertically over the starting leaf. The imaginary spiral line, thus drawn, is known as the **genetic spiral**, and the vertical line, i.e. the vertical row of leaves, known as the **orthostichy** (*orthos*, straight; *stichos*, line).

(1) **Phyllotaxy ½ or 2-ranked or distichous** (fig. 172). In grasses, bulrush (*Typha*; B. HOGLA; H. PATER), traveller's tree (*Ravenala*; B. PANTHA-PADAP—fig. 171), ginger, butterfly-lily, *Vanda* (B. & H. RASNA—see fig. 50), *Belamcanda* (B. DASBAICHANDI), *Iris*, etc., the third leaf stands over the first, and the genetic spiral makes *one* complete revolution to come to that leaf, and it involves two leaves (leaving out of consideration the first or the third leaf). The fourth leaf stands over the second, the fifth over the first and the third, and so on. Thus there are only two orthostichies, i.e. leaves are arranged in two rows or ranks. Phyllotaxy is, therefore, 2-ranked or distichous (*di*, two; *stichos*, *line*). If now the position of the leaves be marked out on a circle or helix, these are seen to be placed at half the distance of the circle, leaves being equidistant from each other. The phyllotaxy is said to be half and represented by the fraction ½, the numerator indicating the number of turns of the genetic spiral, and the denominator the number of intervening leaves.

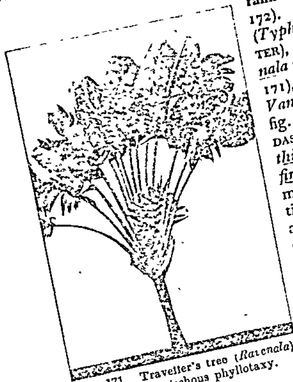


FIG. 171. Traveller's tree (*Ravenala*) showing distichous phyllotaxy.

The genetic spiral makes one complete turn in this case, subtending an angle of 360° in the centre of the circle and it involves two leaves; so the **angular divergence**, that is, the angular distance between any two consecutive leaves, is ½ of 360°, i.e. 180°

(2) **Phyllotaxy $\frac{1}{3}$ or 3-ranked or tristichous** (fig. 173). In sedges (B. & H. MUTHA) the fourth leaf stands vertically over the first one, and the genetic spiral makes one complete turn to reach that leaf, and it involves three leaves. The fifth leaf

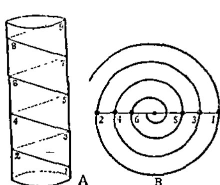


Fig. 172.

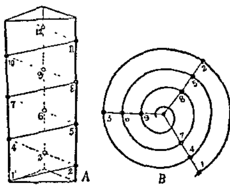


Fig. 173

Phyllotaxy and Angular Divergence Fig. 172. *A*, phyllotaxy $\frac{1}{2}$; *B*, angular divergence 180°. Fig. 173. *A*, phyllotaxy $\frac{1}{3}$; *B*, angular divergence 120°.

stands over the second, the sixth over the third, and the seventh over the fourth and the first. Thus there are three orthostichies, i.e. leaves are arranged in three rows or ranks. If now their position be marked out on a circle or helix, these are seen to be placed at one-third the distance of the circle; so the phyllotaxy is $\frac{1}{3}$ or 3-ranked or tristichous. The **angular divergence** is $\frac{1}{3}$ of 360°, i.e. 120°.

(3) **Phyllotaxy $\frac{2}{5}$ or 5-ranked** or **pentastichous** (fig. 174). In China rose the sixth leaf stands over the first, and the

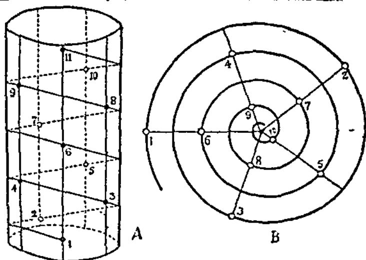


Fig. 174. *A*, phyllotaxy ; *B*, angular divergence 144°.

the axillary bud. The modified leaf carries on a specialized function (see pp. 78-83).

1. **Manufacture of Food.** The primary function of the leaf is to manufacture food material, particularly sugar and starch, during the daytime only, i.e. in the presence of sunlight which is the source of energy to the plant. The leaf manufactures food with the help of chloroplasts contained in it, out of water and carbon dioxide obtained from the soil and the air respectively. The upper side of the leaf is deeper green in colour with more abundant chloroplasts, and also the sunlight falls directly on the upper surface and, therefore, food manufacture normally takes place in this region.

2. **Interchange of Gases.** Through the leaf a regular exchange of gases takes place between the atmosphere and the plant body during the daytime only. To facilitate this exchange numerous very minute openings, called **stomata** (see figs. 422-4), develop, usually on the undersurface of the leaf, and they remain open during daylight only. The gases concerned are oxygen and carbon dioxide. This exchange of gases is mainly for the purpose of *respiration* by all the living cells which absorb oxygen and give out carbon dioxide, and also for the purpose of *food manufacture* by green cells only which absorb carbon dioxide and give out oxygen.

3. **Evaporation of Water.** Root-hairs are continually absorbing water far in excess of the requirement of the plant and this excess is got rid of through the leaf. The excess water evaporates during the daytime through the surfaces of the leaf. The rate of evaporation is, however, much greater through the lower surface than through the upper although sunlight falls directly on the upper surface. This is because of the fact that stomata lying on the lower side and remaining open during the daytime help evaporation; while cuticle (a waxy layer) lying on the upper side checks evaporation. At night the excess water escapes in liquid form through the apices of veins (see fig. 418).

4. **Storage of Food.** Fleshy leaves of Indian aloe (B. GHRITAKUMARI; H. GHIKAVAR), purslane (*Portulaca*; B. NUNIA-SAK; H. & P. KULFA-SAG) and fleshy scales of onion store up water and food material for the future use of the plants. Fleshy and succulent leaves of desert plants always store a quantity of water, mucilage and food material.

[illegible] **Vegetative Propagation.** Leaves of sprout leaf plant [illegible] elephant-ear plant (*Begonia*; see [illegible] ISAGAR; H. HAIZA—see fig. 509)

genetic spiral completes *two* circles to come to that particular leaf. The seventh leaf stands over the second, the eighth over the third, the ninth over the fourth, the tenth over the fifth, and the eleventh over the sixth and the first. Thus there are five orthostichies, i e leaves are arranged in five rows, and because two turns of the genetic spiral involve five leaves, the latter are seen to be placed at two-fifths the distance of the circle Phyllotaxy is, therefore, $\frac{2}{5}$ or 5-ranked or pentastichous. This is the commonest type of alternate phyllotaxy found in plants. The **angular divergence** in this case is $\frac{2}{5}$ of 360°, i e. 144°.

(The same fraction can also be arrived at by adding separately the numerators and the denominators of the two previous cases, e.g. $\frac{1+1}{2+3}=\frac{2}{5}$. The next case will, therefore, be $\frac{1+2}{3+5}=\frac{3}{8}$, and so on. Fractions higher than $\frac{3}{8}$ are not commonly met with.)

Leaf Mosaic. In the floors, walls and ceilings of many temples and decorated buildings we find setting of stones and glass pieces of variegated colours and sizes into a particular pattern. This pattern is known as mosaic. Similarly, in plants we find setting or distribution of leaves in a peculiar pattern This pattern of leaf-distribution is known as leaf mosaic. Leaves are in special need of sunlight for manufacture of food material, and this being so, they tend to fit in with one another and adjust themselves in such a way that they may secure the maximum amount of sunlight with the minimum amount of overlapping. Thus in climbers bearing a dense mass of leaves as in ivy, Indian ivy, railway creeper, etc, leaves are disposed in the pattern of a tile roof. In plants with a rosette of radical leaves or with whorls of leaves it is seen that the upper leaves alternate with the lower ones. In plants with crowded leaves, as in *Acalypha*, etc, *Begonia*, garden nasturtium, with the these are distributed like the glass pieces fitting into a mosaic, smaller leaves fitting into the interspaces of broader ones. Crowded leaves of prostrate plants like wood-sorrel, Indian pennywort, etc., also form a more or less perfect mosaic.



FIG. 175. Leaf mosaic of *Acalypha*.

Functions of the Leaf. Normal functions of the green foliage leaf are threefold: (1) manufacture of food material, (2) interchange of gases between the atmosphere and the plant body, and (3) evaporation of excess of water through the leaf. Besides, the fleshy leaf is used to store up water and food. In a few cases the leaf produces buds on it for vegetative propagation of the plant. The leaf also gives necessary protection to

the axillary bud. The modified leaf carries on a specialized function (see pp. 78-83).

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5. **Vegetative Propagation.** Leaves of sprout leaf plant (*Bryophyllum*: see fig. 34), elephant-ear plant (*Begonia*; see fig. 35) and *Kalanchoe* (B. HEMSAGAR; H. HAIZA—see fig. 509)

produce buds on them for vegetative propagation of such plants. Walking ferns (*Adiantum caudatum, A. lunulatum* and *Polypodium flagelliferum*) reproduce vegetatively by the tips of their leaves. Leaves bow down, and their tips touching the ground strike roots and form a bud which grows into a new plant (see fig. 506).

Heterophylly. Many plants bear different kinds of leaves on the same individual plant. This condition is known as

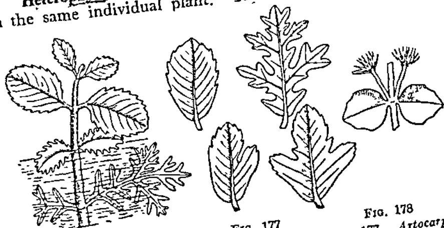


FIG. 176 FIG. 177 FIG. 178

Heterophylly. Fig. 176. *Cardenthera triflora.* Fig. 177. *Artocarpus chaplasha.* Fig 178. *Hemiphragma heterophyllum.*

heterophylly (*heteros*, different; *phylla*, leaves). Heterophylly is met with in many aquatic plants, particularly in those growing in running water. Here the floating leaves and the submerged leaves are of different kinds; the former are generally broad, more or less fully expanded, and undivided or merely lobed, while the latter are narrow, ribbon-shaped, linear or much dissected. Heterophylly in water plants is regarded as an adaptation to two different conditions of the environment. Among them water crowfoot (*Ranunculus aquatilis*), *Cardenthera triflora* (fig. 176), etc., show heterophylly, with the submerged leaves much segmented and the floating (or aerial) leaves undivided or merely lobed. In water plantain (*Alisma plantago*) and arrowhead (*Sagittaria*; fig. 179) submerged leaves are sometimes narrow and ribbon-shaped, while the upper ones are entire or broadly lobed. All transitions of leaf-forms are found in *Limnophila heterophylla.* Some land plants also exhibit this phenomenon without any apparent reason. Among them *Sterculia alata, Artocarpus chaplasha* (B. CHAPLASH—fig. 177), *Ficus heterophylla* (B. BHUI-DUMUR), etc., show leaves varying from entire to variously lobed structures, and *Hemiphragma heterophyllum* (fig. 178), a prostrate herb found in Darjeeling and Shillong, bears two

kinds of leaves—those on the main stem are ovate and entire, and those on short axillary branches are needle-shaped.

H . . . . . ology is . organs . in, and . ie standpoint of their identical structure and function; or, in other words, we may say that organs which resemble one another in their origin, and are, therefore, morphologically the same, whatever be their structure and function, are said to be *homologous* with one another, and organs which resemble one another in their structure and are adapted to the performance of identical functions, although their origin is different, are said to be

. . . are homologous with axillary buds, i.e. modifications of the latter, and tendrils of pea (see fig. 144) are

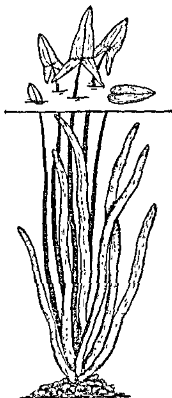


FIG. 179. Arrowhead (*Sagittaria*) showing heterophylly.

H. NAGPHANI), etc , are homo-, but these are analogous with . ves to carry on the functions . l we find that stamens and . lls and megasporophylls of . sporophylls of ferns, and ultimately with vegetative leaves. Similarly sepals and petals are modified vegetative leaves and are homologous with them.

CHAPTER VI

DEFENSIVE MECHANISMS IN PLANTS

The animal kingdom as a whole is directly or indirectly parasitic upon the plant kingdom, and this being so, plants must either fall a victim to various classes of animals, particularly the herbivorous ones, which live exclusively on a vegetable diet, or, they must be provided with special organs or arms of defence, or have other special devices to repulse or

avoid the attack of their enemies. Being fixed to the ground they cannot, of course, manoeuvre, when attacked by animals.

1. Armature

1. **Thorns, Spines, Prickles and Bristles.** These are all sharp-pointed, hard structures, specially developed to ward off herbivorous animals. Small spinous plants, commonly called thistles,—globe thistle (*Echinops*), for example,—are beset with numerous spines and prickles all over their body so that no animal dares attack them.

(1) **Thorns** (see p. 55) are modifications of branches, and originate from deeply-seated tissues of the plant body. They are straight and hard, and can pierce the body of thick-skinned animals. Plants like wood-apple, *Vangueria* (B. MOYENA), lemon, pomegranate, *Duranta*, *Flacourtia* (B. & H. PANIALA), *Carissa* (B. KARANJA; H. KARONDA) and many others are well provided with thorns for self-defence.



Fig. 180. Dagger plant or Adam's needle (*Yucca*).

(2) **Spines** (see p. 79) are modifications of leaves or parts of leaves, and serve the purpose of defence. These are seen in pineapple, date-palm, prickly poppy (see fig. 150), gum tree (*Acacia*), American aloe (*Agave*), dagger plant or Adam's needle (*Yucca*), etc. In dagger plant (*Yucca*; fig. 180) the leaves end in a very sharp and pointed spine, and are directed outwards. Each leaf looks like and behaves as a dagger. Such a plant is naturally left undisturbed by browsing animals. The spines in *Agave* and some other plants are seen to be directed upwards, when the plants are young and small; later on as they grow, the spines are directed horizontally outwards and finally

they all point downwards so that at all stages the plants escape the attack of animals.

(3) **Prickles** (see also p. 30) are also hard and pointed like the th ... l origin ; tl ... e stem, brai ... n rose (see ... e (*Bombax*), *Prosopis* (B. & H. SHOMI ; P. JAND), etc. Cane (*Calamus*; see fig. 57) and *Pisonia* (B. BAGH-ANCHRHA), which are large climbing shrubs, are elaborately armed with numerous sharp prickles and spines for self-defence (as well as for climbing). Animals getting entangled by them often find it very difficult to extricate themselves. In *Solanum xanthocarpum* (B. KANTIKARI : H. KATITA) and egg-plant (*S. ferox*; B. RAMBEGOON) prickles develop on the veins.

(4) **Bristles** are short, stiff and needle-like hairs, usually growing in clusters, and not infrequently barbed. Their walls are often thickened with deposition of silica or calcium carbonate. Bristles are commonly met with in prickly pear (B. PHANI-MANSHA ; H. NAGPHANI) and in many other cacti.

2. **Stinging Hairs.** Nettles (B. BICHUTI ; H. BARHANTA) ... ir leaves or fruits or all over their ... s a sharp siliceous apex ... when touched lightly. ... nto the body, inflicts a wound into which the acid poison of the hair is forced by the sudden pressure exerted on the swollen base of the hair, causing a sharp burning pain, often attended with inflammation. There are various kinds of nettles. *Fleurya* (B. LAL-BICHUTI) and *Tragia* (B. BICHUTI ; H. BARHANTA) are common in waste places. The most poisonous of all nettles is fever or devil nettle (*Laportea*) which is very common in Assam. The stinging hairs of this plant cause a sharp burning pain which lasts for days. The pain is often attended with severe swelling of the part and is intensified on the part being washed. There is another very poisonous nettle, called *Girardinia*. It yields excellent fibres but the poison makes it difficult to collect the plants and extract the fibres, and because of this they have never attained commercial importance. The stinging hairs that develop on the fruits of cowage (*Mucuna*; B. ALKUSHI ; H. & P. KAWANCH), an extensive climber,

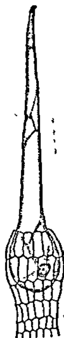


FIG. 181 A stinging hair.

cause inflammation and blisters on any animal that touches them. Stinging hairs are also present in *Urtica dioica*.

3. **Glandular Hairs.** Many plants produce glandular hairs (see figs. 347 & 415) on their leaves, branches and fruits. These glandular hairs secrete a sticky substance which is a kind of gum. If any animal feeds upon such a plant the glands stick to its mouth, and the animal finds it difficult to brush them off. Plants bearing glandular hairs are thus never attacked by grazing animals. Glands of this nature are borne by plants like tobacco, hogweed (*Boerhaavia*; B. PUNARNAVA; H. THIKRI or SANT), *Jatropha* (B. & H. BHARENDA) and *Plumbago* (B. CHITA; H. & P. CHITRAK).

4. **Hairs.** A dense coating of hairs or presence of stiff hairs on the body of the plant is always repulsive to animals as these hairs stick on to their throat and cause a choking sensation, e g. cud-weed (*Gnaphalium*).

II. Other Devices of Defence

5. **Poisons.** Many plants secrete poisonous and irritating substances; such plants are carefully avoided by animals which possess the power of distinguishing between poisonous and non-poisonous ones.

(1) **Latex** is the milky juice secreted by certain plants. It always contains some waste products, and often irritating and poisonous substances so that it causes inflammation and even blisters when it comes in contact with the skin. Plants like madar (*Calotropis*; B. AKANDA; H. & P. AK), *Euphorbia* (B. & H. SIJ and MANSHA-SIJ), oleander (*Nerium*; B. KARAVI; H. & P. KANER), yellow oleander (*Thevetia*; B. KALKE-PHUL; H. & P. PILA-KANER), periwinkle (*Vinca*; B. NAYANTARA; H. SADA-BAHAR), *Ficus* (e.g. banyan, fig, peepul), etc., contain latex in latex cells (see fig. 412); while plants like opium poppy (B. AFING; H. & P. POST), prickly poppy (B. SHEALKANTA; H. PILA-DHUTURA; P. KANDIARI), papaw and some plants of *Compositae* contain latex in latex vessels (see fig. 413).

(2) **Alkaloids** are in many cases extremely poisonous, and a very minute quantity is sufficient to kill a strong animal. There are various kinds of them found in plants, e.g. strychnine in nux-vomica, morphine in opium poppy, nicotine in tobacco, daturine in *Datura*, quinine in *Cinchona*, etc.

(3) **Irritating Substance.** Plants like many aroids, e.g. taro (*Colocasia*; B. KACHU; H. & P. KACHALU), *Amorphophallus* (B. OL; H. KANDA), etc., possess needle-like or otherwise sharp and

pointed crystals of calcium oxalate, i.e. raphides (see figs. 381-3). These crystals, when such plants are fed upon, prick the tongue and the throat and cause irritation. Therefore, such plants never fall a victim to the attack of grazing animals.

6. **Bitter Taste and Repulsive Smell.** These are also effective mechanisms to ward off animals. *Paederia foetida* (B. GANDHAL ; H. GANDHALI) emits a bad smell so that no animal likes to go near it. Plants like sacred basil, mint, *Blumea lacera* (B. KUKURSONGA ; H. KOKRONDA), *Gynandropsis*, etc., also emit a strong disagreeable odour. The fetid smell of the inflorescence of *Amorphophallus* (see fig. 293) is very offensive and nauseating. Margosa, bitter gourd, *Andrographis* (B. KALMEGH ; H. MAHATITA), etc., have a bitter taste and, therefore, never fall a victim.

7. **Waste Products.** Apart from latex, alkaloids, etc., mentioned above, the presence of many other waste products such as tannin, resin, essential oils, raphides and silica also keep plants free from the attack of animals.

8. **Mimicry.** Certain plants also protect themselves against grazing animals by imitating the general appearance, colour, shape or particular feature of another plant or animal,

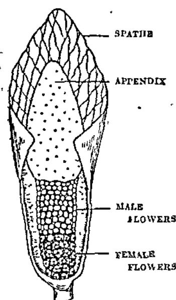


FIG. 182. Devil's spittoon (*Amorphophallus bulbifer*).

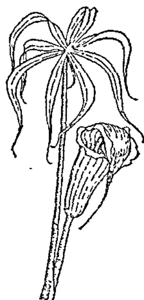


FIG. 183. Snake plant (*Arisaema*).

which has developed special weapon of defence ; for instance, there are certain aroids, (e.g. varieties of *Caladium*) which resemble multi-coloured and variously spotted snakes. Leaves

are also variously spotted and striped in many species of bow-string hemp (*Sansevieria*; B. MURGA; H. MARUL) and other allied plants. Herbivorou
for snakes or some other d
The inflorescences of de
bifer; B. BAN-OL—fig. 182)
hoods of snakes, at least so from a distance. In another aroid, called snake plant (*Arisaema*; fig. 183), common in Shillong during the rains, the spathe is greenish-purple in colour and it expands over the spadix like the hood of the cobra. This act of imitating the appearance, colour or any particular feature of another plant or animal, is called **mimicry** (*mimic*, to imitate).

Plants have also to protect themselves against the attack of many parasitic fungi and gnawing insects, and also against the scorching rays of the sun; this they do by developing cork and bark.

CHAPTER VII

THE INFLORESCENCE

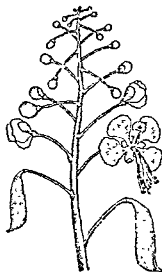
It is seen in many cases that the vegetative axis bears a single flower (solitary flower) either at its apex (terminal flower) or in the axil of a leaf (axillary flower). In other cases it is seen that the floral region is quite distinct from the vegetative region.
is known
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inflorescence have come into existence, and these may primarily be classified into two distinct groups, viz. **racemose or indefinite** and **cymose or definite**.

I. Racemose Inflorescences

Here the main axis of inflorescence does not terminate in a flower, but it continues to grow and give off flowers laterally in *acropetal* succession, i.e. the lower or outer flowers are older than the upper or inner ones, or, in other words, the order of opening of flowers is *centripetal*. The various forms of racemose inflorescence may be described under three heads: *first*, those in which the main axis is elongated; *second*, those in which the main axis is shortened; and *third*, those in which the main axis becomes flattened, concave or convex.

A. With the main axis elongated

1. **Raceme** (fig. 184). The main axis in this case is elongated and it bears laterally a number of flowers which are all stalked, the lower or older flowers having longer stalks than the upper or younger ones, as in radish, mustard, dwarf gold mohur, fever nut (B. NATA; H. & P. KATKARANGA), etc. When the main axis of the raceme is branched and the lateral branches bear the flowers, the inflorescence is said to be a compound raceme or panicle (see fig. 196), as in gold mohur





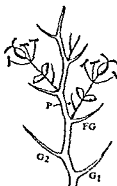




FIG 184 FIG. 185 FIG 186 FIG. 187

Racemose Inflorescences. Fig. 184. Raceme of dwarf gold mohur. Fig. 185. Spike (diagrammatic). Fig. 186. Spikelet of a grass (diagrammatic); G_1, first empty glume; G_2, second empty glume; *FG*, flowering glume (lemma); and *P*, palea. Fig. 187. Female catkin of mulberry.

The main axis of the inflorescence together with the lateral axes, if present, is known as the **peduncle.** The stalk of the individual flower of the inflorescence is called **the pedicel.** In the case of the solitary flower its stalk is regarded and termed as the peduncle. In some flowers such as China rose, gold mohur, etc., the peduncle and the pedicel may, however, be clearly marked out due to the presence of an articulation on the floral axis. When the peduncle of an inflorescence is short and dilated forming a sort of convex platform, as in sunflower, or becoming hollow and pear-shaped, as in fig (*Ficus*), it is often called **receptacle.** The unbranched, often leafless peduncle arising out of the underground stem in the midst of radical leaves and ending in a single flower, as in lotus, or in an inflorescence, as in onion, tuberose, etc., is known as the **scape** (see also p. 34).

2. **Spike** (fig. 185). Here also the main axis is elongated and the lower flowers are older, opening earlier than the upper ones, as in raceme, but the flowers are sessile, that is, without any stalk. Examples are seen in *Adhatoda* (B. BASAK; H. ADALSA; P. BASUTI), amaranth (*Amaranthus*; B. NATE-SAK;

H. & P. CHULAI), chaff-flower (*Achyranthes*; B. APANG; H. LATJIRA; P. KUTRI), etc.

3. **Spikelets** (fig. 186). These are very small spikes with shortened axis bearing one or few flowers. Spikelets are arranged in a spike, raceme or panicle, and may be sessile or stalked on the main inflorescence. Each spikelet bears at its base three scales or bracts, called *glumes*, one placed a little above the other. Of these the lowest two glumes are sterile, i.e. without any flower in their axil, and are called *empty glumes*; while the third one bears a flower in its axil, and is called the *flowering glume* or *lemma*. Opposite to the lemma there is a small 2-nerved bracteole, called the *palea*. The flower remains enclosed by the lemma and the palea. Succeeding flowers likewise occur within the lemma and the palea. Flowers and glumes are arranged on the spikelet in two opposite rows. Spikelets are characteristic of the grass family, e.g. grasses, paddy, wheat, sugarcane, bamboo, etc.

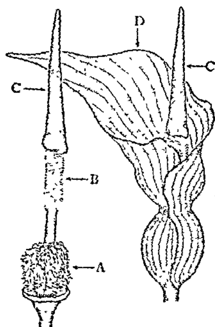


FIG 188 Spadix of an aroid (*Typhonium*), *A*, female flowers; *B*, male flowers; *C*, appendix; and *D*, spathe.

4. **Catkin** (fig. 187). It is a spike with a long and pendulous axis which bears unisexual flowers only, e.g. mulberry (*Morus*), *Acalypha densiflora*, birch (*Betula*) and oak (*Quercus*).

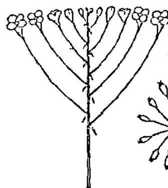
5. **Spadix** (fig. 188). It is also a spike with a fleshy axis, which is enclosed by one or more large, often brightly coloured bracts, called spathes, as in aroids, banana and palms. The spadix is found in monocotyledons only.

B. With the main axis shortened

6. **Corymb** (fig. 189). Here the main axis is comparatively short, and the lower flowers have much longer stalks or pedicels than the upper ones so that all the flowers are brought more or less to the same level, as in candytuft (*Iberis*) and wall-flower.

7. **Umbel** (figs. 190-1). Here the primary axis is shortened, and it bears at its tip a group of flowers which

have pedicels of more or less equal lengths so that the flowers are seen to spread out from a common point. In the umbel there is always a whorl of bracts forming an involucre, and each flower develops from the axil of a bract. Commonly the umbel is branched (**compound umbel**) and the branches bear the flowers, as in anise or fennel, coriander, cumin, carrot, etc. Sometimes, however, it is simple or unbranched (**simple umbel**),



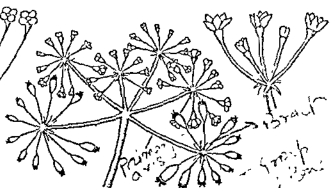




Fig. 189 Fig. 190 Fig. 191

Fig 189. Corymb (diagrammatic). Umbels. Fig. 190. A compound umbel. Fig. 191. A simple umbel.

the main axis directly bearing the flowers, as in Indian pennywort (B. THULKURI ; H. & P. BRAHMIBOOTI) and wild coriander (*Eryngium* ; B. BAN-DHANIA). Umbel is characteristic of coriander family or *Umbelliferae*.

C. With the main axis flattened

8. **Head or Capitulum** (fig. 192). Here the main axis or receptacle is suppressed, becoming almost flat, and the flowers

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usually of two kinds—**ray florets** (marginal strap-shaped ones) and **disc florets** (central tubular ones). The head may also consist of only one kind of florets. The inflorescence is usually

ore whorls of bracts form-

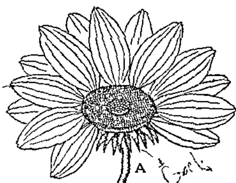
head or capitulum

Compositae (e.g. sunf

Tridax, etc.). It

ive plant, *Antho*

Capitulum is regarded as one of the most perfect types of inflorescence. The individual flowers are comparatively very small, but being massed together in heads they add to greater conspicuousness and at the same time effect a considerable saving of material in the construction of the corolla and other floral parts. Further a single insect may pollinate many flowers in a short time without having to fly from one flower to another.



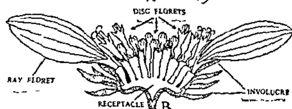


FIG 192. Head or capitulum. *A*, a head (a few ray florets removed to show the involucre); *B*, a head in longitudinal section.

II. Cymose Inflorescences

Here the growth of the main axis is soon checked by the development of a flower at its apex, and the lateral axis which develops below the terminal flower also ends in a flower and, therefore, its growth is also checked. The flowers may be with or without stalks. In the cymose inflorescence the flowers develop in *basipetal* succession, i.e. the terminal flower is the oldest and the lateral [illegible] words, the order of opening of [illegible] cymose inflorescence may be uni[illegible]

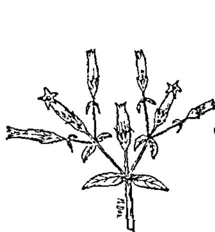
1. **Uniparous or M[illegible] C[illegible]** [illegible] produce). In this type [illegible]

[illegible]

forming a sort of helix, as in *Begonia*, rush (*Juncus*), many [illegible] nd day lily (*Hemero-* [illegible] be a helicoid (or one- [illegible] and when the lateral branches develop on alternate sides, evidently forming a zigzag, as in cotton, sundew, heliotrope (B. HATISUR ; H. HATTASURA) and

Freesia, the cymose inflorescence is said to be a **scorpioid** (or alternate-sided) **cyme** (fig. 194).

In *monochasial* cyme successive axes may be at first zigzag or curved, but subsequently become straightened due to rapid



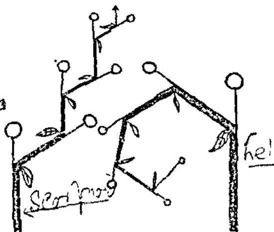


FIG. 193 FIG. 194 FIG. 195

Cymose Inflorescences. Fig. 193. Biparous cyme. Fig. 194. Scorpioid cyme. Fig. 195 Helicoid cyme.

growth thus forming a central or pseudo-axis. This type of inflorescence is called **a sympodial cyme.** This may be distinguished from the racemose type by examining the position of a bract to a flower; in a sympodial cyme a bract appears opposite to a flower, while in a racemose type a bract appears at the base of a flower.

2. **Biparous or Dichasial Cyme** (*bi*, two; *parere*, to produce). In this type of inflorescence the main axis ends in a flower and at the same time it produces two lateral younger flowers or two lateral branches. The lateral and succeeding branches in their turn behave in the same manner (fig. 193). This is **true cyme.** Examples are seen in pink, jasmine, teak, night jasmine, *Ixora* (B. RANGAN; H. GOTAGANDHAL), soapwort (*Saponaria*; B. SABUNI; H. MUSNA), etc.

3. [illegible] In this kind of cymose infloresc [illegible] nds in a flower, and at the sam [illegible] nber of lateral flowers around. [illegible] eral flowers developing more or [illegible] inflorescence looks like an umb [illegible] from the latter by the opening of the middle flower first. This is seen in madar (B. AKANDA; H. AK) and *Hamelia patens*.

Compound and Mixed Forms. When the main axis of the inflorescence is branched and the branches bear the flowers, the inflorescence is said to be compound; as, for example, when raceme is branched it is called a compound raceme or **panicle** (fig. 196), as in gold mohur (B. KRISHNACHURA), margosa (B. & H. NIM), dagger plant, etc. Similarly, other compound forms are pr [illegible] as [illegible] as [illegible] as [illegible] [illegible] anise; [illegible] globe [illegible] ot also infrequent to find mixed inflorescences. There may be combinations of two racemose types, e.g. raceme and spike, raceme and umbel or some other combination, or even racemose and cymose types may be mixed up together, as in madar, *Ixora*, *Clerodendron* (B. & H. BHANT), etc.

FIG. 196. A panicle

III. Special Types

1. **Cyathium** (fig. 197). This is a special kind of inflorescence found in *Euphorbia*, e.g. poinsettia (B. LAL-PATA), spurges (B. SIJ, MANSHA-SIJ, BAJ-BARAN), etc., and also in jew's slipper (*Pedilanthus*; B. RANG-CHITA). In cyathium there is a cup-shaped involucre, often provided with nectar-secreting glands. The involucre encloses a single female flower (reduced to a pistil) in the centre, seated on a comparatively long stalk, and a number of male flowers (each reduced to a solitary stamen) around this, seated on short stalks. *That each stamen* is a single male flower is evident from the facts that it is articulated to a stalk and that it has a

FIG. 197. *Cyathium* of poinsettia. *A*, cyathium, *B*, the same in longitudinal section; *a*, female flower; *b*, male flowers. Note the involucre.

scaly bract at the base. The flowers follow centrifugal (cymose) order of development. The female flower in the centre matures first, and then the stamens (male flowers) just surrounding it, and ultimately the marginal ones.

2. **Verticillaster** (fig. 198). This is a condensed form of dichasial cyme with a cluster of sessile or almost sessile flowers in the axil of a leaf, forming a false whorl at the node. The first axis gives rise to two lateral branches and these branches and the succeeding ones bear only one branch each on alternate sides. This kind of inflorescence is found in several members of basil family or *Labiatae*. In this family as the leaves are opposite, two clusters of flowers are found opposite each other at the node. Examples are seen in country borage (*Coleus*; B. & H. PATHUR-CHUR), mint (*Mentha*; B. PUDINA; H. & P. PODINA), *Leonurus* (B. DRONA; H. HALKUSHA), *Leucas* (B. SWET-DRONA; H. CHOTA-HALKUSHA), etc. In sacred basil (B. & H. TULSI) the verticillaster is reduced to a dichasial cyme, succeeding branches remaining undeveloped.



FIG 198. Verticillaster of *Coleus*. *A*, verticillaster; *B*, diagram of verticillaster.

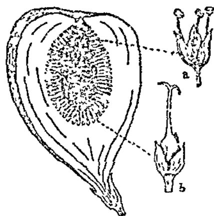
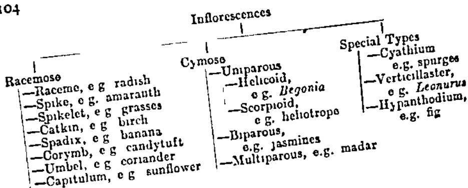


FIG 199. Hypanthodium of fig (*Ficus*). *a*, male flower; *b*, female flower.

3. **Hypanthodium** (fig. 199). When the receptacle forms a hollow cavity with an apical opening guarded by scales, and the flowers are borne on the inner wall of the cavity, the inflorescence is a hypanthodium, as in *Ficus* (e.g. banyan, fig, peepul, etc.). Here the female flowers develop at the base of the cavity and the male flowers higher up towards the apical pore.



CHAPTER VIII

THE FLOWER

The **flower** is a metamorphosed shoot, meant essentially for the reproduction of the plant. It consists of a collection of *sporophylls* or spore-bearing leaves with or without some accessory parts. The sporophylls are of two kinds—microsporophylls or **stamens** and megasporophylls or **carpels.** Both kinds of sporophylls may be present in a flower, or only one may be seen in some types.

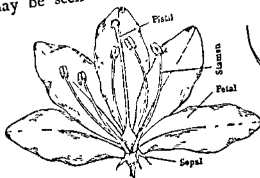


Fig 200

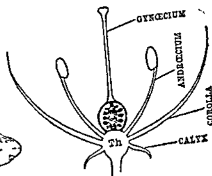


Fig. 201

Fig. 200 Parts of a flower. Fig. 201. A flower in longitudinal section showing the position of the whorls on the thalamus (*Th*).

Parts of a Flower (figs. 200-2)

The flower is commonly borne on a short or long axis. The axis itself is made up of two regions, viz. the **pedicel** which is the stalk of the flower, and the **thalamus** which is the swollen end of the axis with the floral leaves inserted on it. The pedicel may be short or long or even absent. A typical flower consists of *four* different types of floral leaves arranged in *four* whorls in a definite order, one just above

the other (fig. 201), on the exceedingly short thalamus. Of the four whorls the lower two are called **helping** or **accessory** whorls and the upper two called **essential** or **reproductive** whorls because only these two are directly concerned in reproduction.

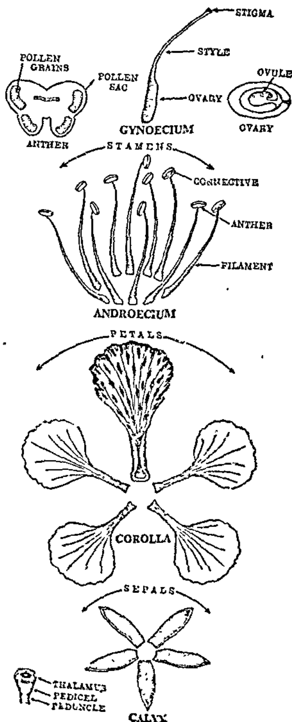


FIG. 202. Flower of gold mohur (*Delonix regia*) dissected out.

1. **Calyx** is the first or the lowermost whorl of the flower or the first accessory whorl of it, and is composed of a number of green leafy **sepals.**

2. **Corolla** is the second whorl of the flower or the second accessory whorl of it, and consists of a number of usually brightly coloured **petals.**

3. **Androecium** (*andros*, male) is the third or the male whorl; its component parts are called **stamens** or *microsporophylls* which are regarded as the male organs of the flower. Each stamen is made of three parts—**filament, anther** and **connective.** The anther bears four chambers or **pollen-sacs,** each filled

a granular mass of small (male) spores, called **pollen grains** or microspores.

4. **Gynoecium** (gyne, female) or **pistil** is the fourth or the female whorl, and its component parts are called **carpels** or *megasporophylls* which are regarded as the *female organs* of the flower. The pistil is made of three parts—**ovary, style** and **stigma.** The ovary bears some minute egg-like bodies known as the **ovules.** Each ovule encloses a large oval cell known as the **embryo-sac** which is the female spore or megaspore (see fig. 286).

The flower is said to be **complete** when all the four whorls are present, and **incomplete** when any of them is absent. When both stamens and carpels are present the flower is said to be **perfect** or **bisexual** or **hermaphrodite,** regardless of whether the sepals or petals are present or absent, and when any of them is absent the flower is said to be **imperfect or unisexual.** The imperfect or unisexual flower may, therefore, be **staminate** or **male** when only stamens are present, or, **pistillate** or **female** when only carpels are present. When both stamens and carpels are absent from a flower it is said to be **neuter,** and when bisexual and unisexual flowers, and sometimes also neuter, are borne by a single plant, they are said to be **polygamous,** as in *Polygonum* (B. PANIMARICH ; P. NARRI), mango and wild mangosteen (B. GAB ; H. KENDU). When the calyx and corolla do not differ much in shape and colour, they together are said to form the **perianth** of the flower, as in lilies, Indian tuberose, onion, garlic, plantain, palms, etc. When the perianth is green in colour it is said to be *sepaloid*, and when coloured otherwise like petals it is *petaloid*. The leaves of the perianth may be free or united, and accordingly it (the perianth) is said to be *polyphyllous* or *gamophyllous*.

The flower is said to be **cyclic** when sepals, petals, stamens and carpels are arranged in circles or whorls round the thalamus, as in most flowers, and **acyclic** when these are spirally arranged, as in water lily, *Magnolia* (B. DULEE-CHAMPA), *Michelia* (B. CHAMPA ; H. CHAMPAK), etc. The flower may be **hemicyclic** also when some parts are cyclic and others acyclic, as in rose.

THALAMUS

Nature of the Thalamus. The **thalamus** (see fig. 201), also called torus or receptacle, is the suppressed swollen end of the flower-axis on which are inserted the floral leaves, viz. sepals,

petals, stamens and carpels. In most flowers this thalamus is exceedingly short; but in a few cases it becomes elongated, and then it shows distinct nodes and internodes. Thus the

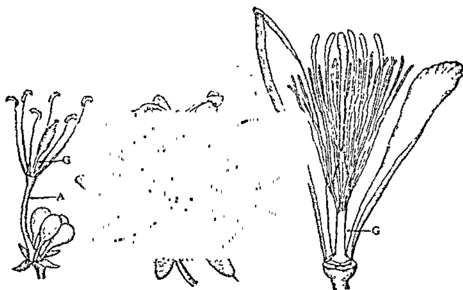


FIG. 203 FIG. 204 FIG. 205
Thalamus. Fig. 203. Flower of *Gynandropsis*; *A*, androphore; *G*, gynophore. Fig. 204. Passion-flower; *A*, androphore. Fig. 205. Flower of *Pterospermum*; *G*, gynophore (with the staminal tube adnate to it).

internode between the calyx and the corolla, when elongated, is known as the **anthophore** (*anthos*, a flower; *phore*, a stalk), as in *Silene* (a genus of pink family). In *Gynandropsis* (B. SWET-HURHURE; H. HURHUR—fig. 203) and passion-flower (B. & H. JHUMKA-LATA—fig. 204) the internode between the

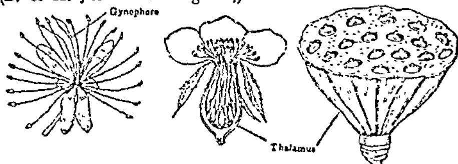


FIG. 206 FIG. 207 FIG. 208
Thalamus (*contd.*). Fig. 206. Flower of *Capparis*. Fig. 207. Rose (in section). Fig. 208. Lotus.

corolla and the androecium is considerably elongated, and is known as the **androphore** (*andros*, male). In *Capparis* (B. KANTA-GURKAMAI; H. HIUN; P. HIUS—fig. 206), *Gynandropsis*

(fig. 203) and *Pterospermum* (B. MOOCH-KANDA; H. KANAK-CHAMPA—fig. 205) the axis between the androecium and the gynoecium is elongated, and is known as the **gynophore** (*gyne*, female). When both androphore and gynophore develop they are together known as the **gynandrophore**, as in *Gynandropsis*. In *Magnolia* (B. DULEE-CHAMPA) and *Michelia* (B. CHAMPA; H. CHAMPAK) the thalamus is fleshy and elongated, and bears the floral leaves spirally round it. In rose (fig. 207) it is concave and pear-shaped. The thalamus of lotus (fig. 208) is spongy and top-shaped. When the thalamus becomes prolonged upwards into a slender axis with the carpels remaining attached to it at first and separating from it on maturity it (the axis) is called **carpophore**, as in balsam (*Impatiens*), anise (fig. 209), coriander, cumin, *Geranium*, etc.

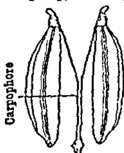


FIG. 209 Fruit of anise.

Position of Floral Leaves on the Thalamus. There is considerable variation in the relative positions of the different whorls of flowers with respect to their ovary. These relationships are of three kinds: **hypogyny**, **perigyny** and **epigyny** (figs 210-2).

1. **Hypogyny.** In a hypogynous flower the thalamus is conical, convex, flat or slightly concave, and the ovary occupies the highest position on the thalamus; while the stamens, petals and sepals are separately and successively inserted below the ovary. The ovary is said to be *superior* and the rest of the floral members *inferior*. Examples are seen in mustard, brinjal, China rose, *Magnolia*, etc.

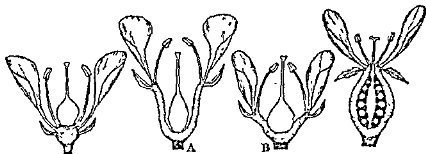


FIG. 210 FIG. 211 FIG. 212
Position of Floral Leaves on the Thalamus. *Fig.* 210. Hypogyny. *Fig.* 211. Perigyny (two types—*A* & *B*). *Fig.* 212. Epigyny.

2. **Perigyny.** In a perigynous flower the margin of the thalamus grows upward to form a cup-shaped structure, called

the calyx-tube, enclosing the ovary but remaining free from it, and carrying with it the sepals, petals and stamens. The ovary is said to be *half-inferior*. In some perigynous flowers the ovary may be partially sunken in the thalamus. Examples are seen in rose, plum, primrose, peach, prune, crepe flower and sometimes in *Leguminosae* (e.g. pea, bean, gold mohur, etc.).

3. **Epigyny.** In an epigynous flower the margin of the thalamus grows further upward, completely enclosing the ovary and getting fused with it, and bears the sepals, petals and stamens above the ovary. The ovary in this case is said to be *inferior*, and the rest of the floral members *superior*. Examples are seen in sunflower, guava, gourd, cucumber, apple, pear, etc.

BRACTS

Bracts are special leaves from the axil of which a solitary flower, or a cluster of flowers, arises. When a small leafy or scaly structure is present on the flower-stalk (pedicel) in any part of it, it goes by the name of **bracteole.** Bracts vary in size, colour and duration. Their primary function is to protect the floral bud from sun and rain. For this purpose they often become much enlarged, and enclose the whole cluster of flowers. When green in colour they manufacture food material like ordinary green leaves. Sometimes they become brightly coloured, and then they serve to attract insects for pollination.

Kinds of Bracts. Bracts have received special names according to their size, colour and arrangement.

1. **Leafy bracts,** when they are green, flat and leaf-like in appearance, as in *Acalypha* (B. MUKTO-JHURI ; H. KUPPI), *Adhatoda* (B. BASAK ; H. ADALSA ; P. BASUTI), *Gynandropsis*, etc.

2. **Scaly bracts,** when the bracts are of a scaly nature, that is, small and thin, as in the central florets of sunflower.

3. **Spathe** (see fig. 188), when the bract is large and completely surrounds a flower, or more commonly a cluster of flowers, and protects the latter while they are young, as in aroids, banana, palms, maize cob, etc. The spathe is often brightly coloured, and then it attracts insects for pollination.

4. **Petaloid bracts** (fig. 213), when they become coloure and showy, as in glory of the garden (B. BAGAN-BILAS) poinsettia (B. LAL-PATA—see fig. 798).

5. **Involucre** (fig. 214), when one or more whorls of bracts are present around a flower, as in Indian strawberry (*Fragaria*), or around a group of flowers, as in sunflower, marigold, etc. The bracts of the involucre may be united in one or more whorls or they may remain free. A peculiar boat-shaped involucre is found in *Ipomoea pileata*.

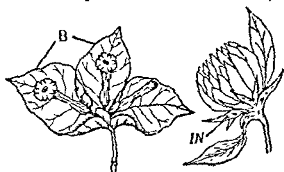


FIG 213 FIG. 214

Kinds of Bracts Fig. 213. Petaloid bracts (*B*) of glory of the garden. Fig. 216. Involucre (*IN*) of sunflower.

6. **Epicalyx**, when when one or more whorls of bracteoles develop at the base of the calyx, as in *China rose, cotton*, etc.

7. **Glumes.** These are special bracts, small and dry, found only in grass family (see fig. 186) and sedge family.

FLOWER IS A MODIFIED SHOOT

The following facts may be cited to prove that the *thalamus* is a modified branch; *sepals, petals, stamens* and *carpels* are modified vegetative leaves; and the *flower* as a whole a modified vegetative bud.

permum (B. MOOCH-KANDA; H. KANAK-CHAMPA), etc. The thalamus may, therefore, be regarded as a modified branch.

2. Thalamus sometimes shows monstrous development, i.e. after bearing the floral members it prolongs upwards and bears ordinary foliage leaves. The thalamus thus behaves as a branch. Examples are sometimes seen in rose (fig. 215), larkspur, pear, etc.

3. A floral bud like a vegetative bud is either terminal or axillary in position.

4. The arrangement of sepals, petals, etc. on the thalamus is the same as that of the leaves on the stem or the branch, being either whorled, alternate (spiral) or opposite. Although most flowers show a whorled arrangement, a spiral arrange-

ment is met with in flowers like water lily, cactus, *Magnolia*, etc.

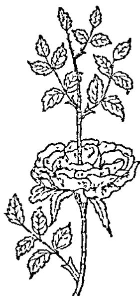


Fig. 215. monstrou of the

5. Even the arrangement of sepals and petals with respect to each other (aestivation) is the same as that of the foliage leaves (prefoliation).

6. The foliar nature of sepals and petals is evident from their similarity to leaves as regards structure, form and venation; in fact, in *Mussaenda* (fig. 216) one of the sepals becomes modified into a distinct white or coloured leaf. In green rose the petals are leaf-like in structure and green in colour. But stamens and carpels are unlike leaves in all respects. Their homology with leaves can be made out from certain flowers. Thus water lily (figs. 217-8) shows a gradual transi- ls and from petals ivated rose shows n wild rose there xplanation is that : modified into many petals. China rose and *Hibiscus* ..., H. & P. GULIAJAIB)



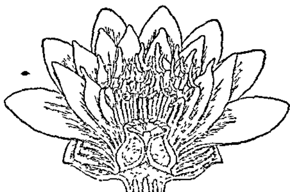


Fig. 216 Fig 217

Fig. 216. *Mussaenda* flower with a sepal modified into a leaf. Fig. 217 Water lily flower showing transition of floral parts.

some or ... ls. Sometime ... seen to become ... into petals. In *Canna* the stamens and the style have become petaloid.

7. The inflorescence axis normally bears flowers. Sometimes, as in American aloe (*Agave*; see fig. 512), some of the floral buds become modified into vegetative buds, called bulbils,

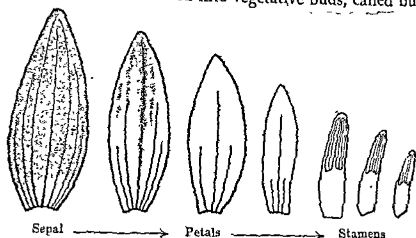


FIG. 218. Transition of floral parts in water lily flower.

for vegetative reproduction. In pine-apple also the inflorescence axis bears one or more vegetative buds or bulbils (see fig. 514) for vegetative propagation. Such bulbils thus show a reversion to ancestral forms, i.e. the forms from which they have been derived.

Symmetry of the Flower. A flower is said to be symmetrical when it can be divided into two exactly equal halves by *any* vertical section passing through the centre. Such a flower is also said to be **regular** or **actinomorphic** or radially symmetrical. Examples are found in mustard, *Datura*, brinjal, chilli, etc. When a flower can be divided into two similar [illegible]

A flower is also said to be symmetrical when all the whorls have an equal number of parts or when the number in one whorl is a multiple of that of another. Such a symmetrical flower is said to be **isomerous** (*isos*, equal; *meros*, a part). An isomerous flower may be *bimerous*, *trimerous*, *tetramerous* or *pentamerous*, according as the number of parts in each whorl is 2, 3, 4 or 5 or any multiple of it. Trimerous flowers are common among monocotyledons, and pentamerous flowers among dicotyledons. When the number in *all* the whorls is neither the same nor any multiple, the flower is said to be **heteromerous** (*heteros*, different).

(1) CALYX

Calyx is the first or the lowermost whorl of the flower, and consists of a number of **sepals**. It is usually green (*sepaloid*), but sometimes it becomes coloured (*petaloid*), as in gold mohur, dwarf gold mohur and garden nasturtium. It varies in shape, size and colour; it may be **regular, zygomorphic,** or **irregular.** The sepals may remain free from each other or they may be united together; in the former case the calyx is said to be **polysepalous** (*poly*, many), as in mustard, radish, etc.; and in the latter it is **gamosepalous** (*gamo*, united), as in brinjal, chilli, China rose, etc. The calyx is sometimes altogether absent from a flower, or it may be modified into *scales*, as in sunflower, marigold, etc., or into *pappus* (see fig. 335), as in *Tridax* and many other plants of *Compositae*. In *Mussaenda* (H. BEBINA—see fig. 216) one of the sepals becomes large, leafy and perfectly white or brightly coloured.

Functions. (1) *Protective.* The primary function of the calyx is to enclose the flower in its bud stage and protect it from sun and rain. In *Plumbago* (B. CHITA; H. CHITRAK) the calyx is provided with sticky glands, and then it serves to ward off herbivorous animals. (2) *Assimilatory.* When green in colour it assimilates the carbon dioxide of the atmosphere and manufactures sugar and starch like the green leaf. (3) *Attractive.* When coloured and showy, it attracts insects for pollination. (4) *Special function.* In many flowers of *Compositae* the calyx is modified into a whorl of hairs, known as the **pappus** (fig. 335). It is persistent in the fruit and helps its distribution by the wind.

Duration. If the calyx falls off as soon as the floral bud opens it is said to be **caducous,** as in poppy. The calyx is said to be **deciduous** if it falls off when the flower withers. But sometimes it remains adherent to the fruit; then it is known as **persistent.** A persistent calyx may assume a withered appearance, as in cotton, or it may continue to grow and become fleshy, as in *Dillenia* (B. & H. CHALTA).

(2) COROLLA

Corolla is the second whorl of the flower, and consists of a number of **petals.** The petals are often brightly coloured and sometimes scented, and then their function is to attract insects for *pollination*; they are rarely sepaloid. In the bud stage of the flower the corolla encloses the essential organs, namely, stamens and carpels, and protects them from external heat and rain.

Like the calyx, the corolla may also be **regular** or radially symmetrical, **zygomorphic** or bilaterally symmetrical, or irregular (see p. 112). Like the calyx again, the corolla may be **gamopetalous** or **polypetalous**, according as the petals are united or free. In the former case the petals may be united partially or wholly. In the polypetalous corolla each petal may sometimes be narrowed below, forming a sort of stalk, known as the *claw*, and expanded above; this expanded portion is called the *limb*. The claw corresponds to the petiole, and the limb to the blade of a leaf. In the gamopetalous corolla the lower tubular portion is known as the *tube* and the upper expanded portion the *limb*. The limb may have a number of *lobes* corresponding to the number of petals. The portion of the tube which opens into the limb is called the *throat*.

Forms of Corollas. The form of the corolla depends upon whether it is regular or zygomorphic, and gamopetalous or polypetalous, and upon shapes and sizes of petals and their arrangement in the flower. The various forms may be studied under the following four main heads:

I. Corollas—Regular and Polypetalous

1. **Cruciform** (fig. 219). The cruciform corolla consists of four free petals, each differentiated into a claw and a limb, and these are arranged in the form of a cross, as in mustard family or *Cruciferae*, e.g. mustard, radish, cabbage, cauliflower, candytuft, etc.

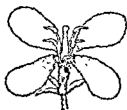


Fig. 219

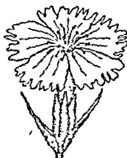


Fig. 220

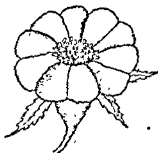


Fig. 221

Forms of Corollas. Fig. 219. Cruciform. Fig. 220. Caryophyllaceous. Fig. 221. Rosaceous.

2. **Caryophyllaceous** (fig. 220). This form of corolla consists of five petals with comparatively long claws, and the limbs of the petals are placed at right angles to the claws, as in pink (*Dianthus*).

3. **Rosaceous** (fig. 221). This form consists of five petals, as in the previous case, but these have very short claws or

none at all, and the limbs spread regularly outwards, as in rose, tea, prune, etc.

II. Corollas—Regular and Gamopetalous

1. **Campanulate or Bell-shaped** (fig. 222). When the shape of the corolla resembles that of a bell, as in gooseberry (B. TEPARI ; H. & P. RASHBHARI), bell flower (*Campanula*), wild mangosteen (B. GAB ; H. KENDU), etc., it is said to be campanulate.

2. **Tubular** (fig. 223). When the corolla is cylindrical or tube-like, that is, more or less equally expanded from base to apex, as in the central florets of sunflower, it is said to be tubular.

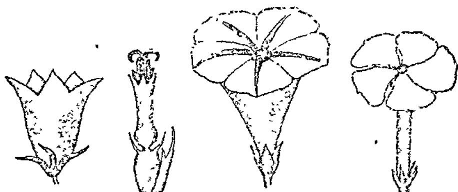


Fig. 222 Fig. 223 Fig. 224 Fig. 225

Forms of Corollas (*contd.*). Fig 222. Campanulate. Fig 223. Tubular Fig. 224. Funnel-shaped. Fig 225 Rotate.

3. **Infundibuliform or Funnel-shaped** (fig. 224). When the corolla is shaped like a funnel, that is, gradually spreading outwards from a narrow base, as in thorn-apple (*Datura* ; B. DHUTRA ; H. DHUTURA), water bindweed (B. & H. KALMI-SAK), railway creeper, morning glory, yellow oleander, etc., it is said to be infundibuliform.

4. **Rotate or Wheel-shaped** (fig. 225). When the tube of the corolla is short and the limb of it is at a right angle to it, the corolla having more or less the appearance of a wheel, as in night jasmine (B. SHEPHALIKA ; H. HARSINGHAR), periwinkle (B. NAYANTARA ; H. SADA-BAHAR), etc., it is said to be rotate.

III. Corolla—Zygomorphic and Polypetalous

1. **Papilionaceous or Butterfly-like** (fig. 226). Its general appearance is like that of a butterfly. It is composed of five petals, of which the outermost one is the largest and known as **the standard or vexillum**, the two lateral ones are known as

the wings or alae, and the two innermost ones are the smallest and are together known as the keel or carina. These two are apparently united to form a boat-shaped cavity. Examples are found in pea family or *Papilionaceae*, e.g. pea (figs. 226-8), bean, gram, butterfly pea (*Clitoria*; B. APARAJITA; H. APARAJIT), rattlewort (*Crotalaria*; B. ATASHI; H. JHUNJHUNIA), etc.

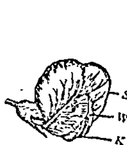


Fig. 226

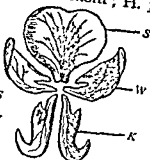


Fig. 227

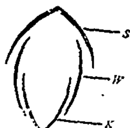


Fig. 228

Fig. 226 Papilionaceous flower of pea. Fig. 227. Petals of the same opened out. Fig. 228. Vexillary aestivation of papilionaceous corolla. S, standard or vexillum; W, wing; K, keel.

IV. Corollas—Zygomorphic and Gamopetalous

1. **Bilabiate or Two-lipped** (fig. 229). In this form the limb of the corolla is divided into two portions or lips—the upper and the lower, with the mouth gaping wide open. Examples may be seen in sacred basil (*Ocimum*; B. & H.



Fig. 229

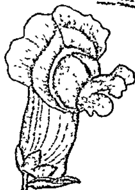


Fig. 230



Fig. 231

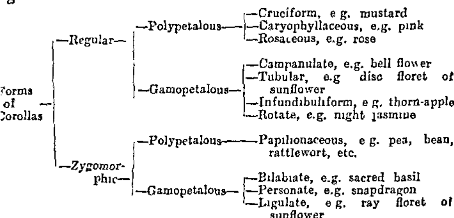
Forms of Corollas (*contd.*). Fig. 229. Bilabiate. Fig. 230. Personate. Fig. 231. Ligulate.

TULSI), *Leonurus* (B. DRONA; H. HALKUSHA), *Leucas* (B. SWET-DRONA; H. CHOTA-HALKUSHA), *Hygrophila* (B. KULEKHARA; H. GOKHULA-KANTA), *Adhatoda* (B. BASAK; H. ADALSA; P. BASUTI), etc.

2. **Personate or Masked** (fig. 230). This is also two-lipped like the previous one, but in this case the lips are placed so

ear to each other as to close the mouth of the corolla. The projection of the lower lip closing the mouth of the corolla is known as the *palate*, as in snapdragon, *Lindenbergia*, etc.

3. **Ligulate or Strap-shaped** (fig. 231). When the corolla forms into a short, narrow tube below, but is flattened above like a strap, as in the outer florets of sunflower, it is said to be ligulate.



...olla or the perianth is somet... appendages of various kinds ... the tube of the corolla is slightly dilated on one side like a pouch or sac; it is then





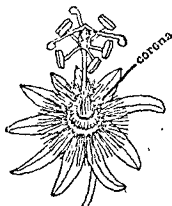

FIG. 232 FIG. 233 FIG. 234 FIG. 235

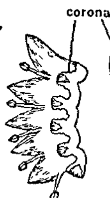
Appendages of Perianth. Fig. 232. Saccate corolla (s') of snapdragon. Fig. 233. Flower of garden nasturtium. Fig. 234. Flower of larkspur. Fig. 235. Flower of balsam. *s*, spur.

said to be **saccate or gibbous** (fig. 232). In some cases, as in balsam, garden nasturtium and larkspur, the perianth is prolonged into a tube, known as the **spur** (figs. 233-5), and it (the perianth) is then said to be spurred. In some flowers a special sac, known as the **nectary**, develops containing nectar.

Sometimes, by a transverse splitting of the corolla, an additional whorl may be formed at its throat. This additional

whorl may be made up of lobes, scales or hairs, free or united, and is known as corona (*crown*). The corona may be well seen in passion-flower (fig. 236), dodder (fig. 237), and oleander





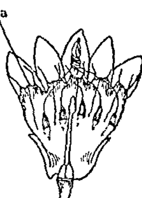
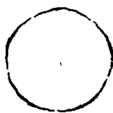


FIG. 236 FIG. 237 FIG. 238

Appendages of Corolla: Corona. Fig 236. Passion-flower Fig. 237 Flower of dodder. Fig. 238 Flower of oleander.

(*Nerium*; fig. 238). A beautiful, cup-shaped corona is seen in daffodil (*Narcissus*). The corona adds to the beauty of the flower and is thus an adaptation to attract insects for pollination.

Aestivation. The mode of arrangement of the sepals or of the petals, more particularly the latter, in a flower-bud with respect to the members of the same whorl (calyx or corolla) is known as **aestivation.** Aestivation is an important character



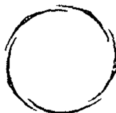






FIG. 239 FIG 240 FIG. 241 FIG. 243

Aestivation of Corolla. Fig. 239. Valvate. Fig. 240. Twisted. Fig. 241. Imbricate. Fig. 242. Vexillary

from the view-point of classification of plants, and may be of the following types:

1. Valvate (fig. 239), when the members of a whorl are in contact with each other by their margins, or when they lie *very close to each other*, but do not overlap, as in custard-apple (B. ATA; H. SHARIFA), bullock's heart (B. NONA; H. RAMPHAL), madar (B. AKANDA; H. & P. AK), *Artabotrys* (B. KANTALI-CHAMPA; H. KANTLLI-CHAMPA), etc.

2. **Twisted or Contorted** (fig. 240), when one margin of the sepal or the petal overlaps that of the next one, and the other margin is overlapped by the third one, as in China rose, cotton, etc. Twisting of the petals may be clockwise or anticlockwise. In China rose, however, it is both clockwise and anticlockwise.

3. **Imbricate** (fig. 241), when one of the sepals or petals is internal being overlapped on both the margins, and one is external and each of the remaining ones is overlapped on one margin and it overlaps the next one on the other margin, e.g. *Cassia*, gold mohur, dwarf gold mohur, etc.

4. **Vexillary** (fig. 242), when there are five petals, of which the posterior one is the largest and almost covers the two lateral petals, and the latter in their turn nearly overlap the two anterior or smallest petals. Vexillary aestivation is universally found in all papilionaceous corollas (see also figs. 226-8), as in pea family or *Papilionaceae*, e.g. pea, bean, butterfly pea, rattlewort, etc.

(3) ANDROECIUM

Androecium (*andros*, male) is the third or the male reproductive whorl of the flower, and is composed of a number of **stamens** which are modified leaves meant to bear male spores or microspores (pollen grains); such microspore-bearing leaves are otherwise called microsporophylls. Each stamen consists of **filament, anther** and **connective** (fig. 243). The filament is the slender stalk of the stamen, and the anther is the expanded head borne by the filament at its tip. Each anther consists usually of two lobes connected together by a sort of midrib known as the **connective.** Each lobe contains within it two chambers or loculi, called the **pollen-sacs** or *microsporangia*; thus there are altogether four loculi in each anther (fig. 244). But in many cases there are only two, and sometimes, as in China rose, lady's finger, cotton, etc., there is only one. Within each pollen-sac there is a fine, powdery or granular mass of cells, called the pollen grains or *microspores*. Pollen grains are produced in large

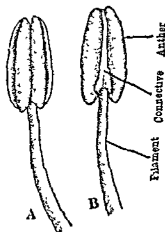


FIG. 243. Two stamens *A*, face of the anther showing four pollen-sacs; *B*, back of the anther showing connective.

quantities in the pollen-sacs, and are often scattered by the

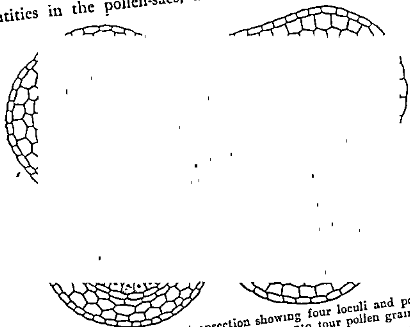


Fig. 244. An anther in transection showing four loculi and pollen grains in tetrads. Each tetrad separates into four pollen grains.

wind like particles of dust, as seen in pine, palms, screwpine, maize, etc. Sometimes, as in gunpowder plant (*Pilea*) and *Urtica*, anthers explode and puffs of pollen grains are seen to be ejected from them. The filament corresponds to the petiole of the leaf, the anther to the leaf-blade, and the connective to the mid-rib. The side of the anther to which the connective is attached is called the *back* and the other side is the *face*. The face is often provided with a longitudinal groove. When the face is turned towards the centre of the flower the anther is said to be **introrse**; and when the face

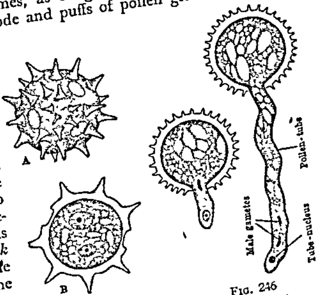
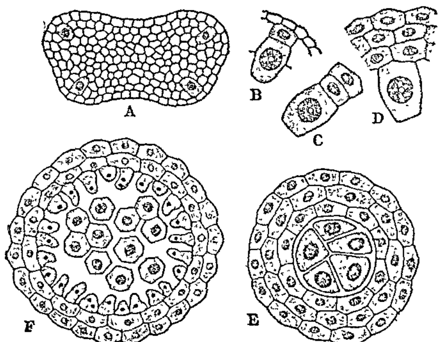
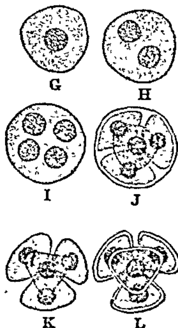


Fig. 245 Fig. 246

Fig. 245. Pollen grains. *A*, an entire grain; *B*, a grain in section showing tube-nucleus (bigger one) and generative nucleus (smaller one). Fig. 246. Growth of the pollen-tube.



is turned outwards it is **extrorse.** When the anther is absent from the stamen, or is very feebly developed without bearing the pollen grains, the stamen is said to be *sterile*; such a sterile stamen is otherwise known as a **staminode,** as in pink, noon flower (*Pentapetes*; B. DUPOHRIA; H. DOPOHORIA), *Pterospermum* (B. MOOCHKANDA; H. KANAK-CHAMPA—fig. 205), etc., and when the filament is absent the anther is said to be **sessile.**



The Pollen. Pollen grains or repro- and are sacs or *microsporangia.* They are very

Fig. 247. *A-F*, development of anther; *G-L*, development of pollen grains. *A*, a young anther in cross-section showing four hypodermal cells; *B*, upper (parietal cell) and lower (sporogenous cell); *C-D*, divisions of parietal cells; *E*, parietal layers with tapetum (innermost layer) surrounding the central sporogenous tissue; *F*, parietal layers, tapetum (fully developed) and pollen-mother cells; *G*, a pollen mother cell; *H I*, nuclear divisions; *J*, cleavage of the protoplast in a tetrahedral manner; *K*, disappearance of the wall of the pollen-mother cell and tetrahedral arrangement of pollen grains; *L*, pollen grains in a tetrad with the formation of exine and intine in each.

minute in size, varying from $\frac{1}{500}$ to $\frac{1}{1000}$ of an inch, and are like particles of dust. Each pollen grain consists of a single microscopic cell, and possesses two coats: the **exine** and the **intine.** The exine is a tough, cutinized layer, which is often provided with spinous outgrowths or reticulations of different patterns, sometimes smooth. The intine, however, is a thin, delicate, cellulose layer lying internal to the exine. In pine the pollen grain is provided with two distinct wings. When the pollen grain has to germinate the intine grows out into a tube, called the **pollen-tube** (fig. 246), through some definite thin and weak slits or pores, called **germ pores,** present in the exine (fig. 245). Sometimes the pore is covered by a distinct lid which is pushed open by the growth of the intine. At first each pollen grain contains only one nucleus; this divides to form two nuclei, of which the larger one is known as the vegetative nucleus or **tube-nucleus** and the smaller one the **generative nucleus.** As the pollen-tube grows it carries with it at its apex the tube-nucleus and the generative nucleus. The generative nucleus soon divides and two male reproductive units are formed, which are known as the **male gametes.** The tube-nucleus then gets disorganized.

Development of Pollen Grains (fig. 247). At an early stage of the anther *four* vertical rows of cells, one at each lobe, with dense protoplasmic contents become apparent (A). Each cell of the row divides into an inner larger cell—the **sporogenous cell** or **archesporium,** and an outer smaller cell—the **parietal cell** (B). The latter divides tangentially into 2 or 3 layers (C). These (parietal) cells again divide repeatedly by radial walls and extend around the sporogenous cell (D) which also begins to divide forming a central group of cells (E). These (sporogenous) cells grow, separate from one another and become the **spore-** or **pollen-mother cells.** The innermost layer of parietal cells, directly abutting upon the sporogenous cells and later the pollen-mother cells, is called the **tapetum** (F). The cells of the tapetum are more or less wedge-shaped and contain one or more nuclei. It is a nutritive tissue supplying food to the pollen grains as they develop. Ultimately the tapetum gets disorganized.

The nucleus of each pollen mother cell (G) divides twice so that four nuclei are formed in it. Of the two successive divisions the first one (H) is meiosis and the second one (I) is mitosis so that each nucleus has half (n) the usual number ($2n$) of chromosomes. The four nuclei so formed are arranged in a tetrahedral manner, and cleavage of the cytoplasm occurs separating the nuclei into four distinct segments—the pollen cells (J). The wall of the mother cell disappears (K) and each pollen cell secretes a thick outer wall—the **exine,** and a thin inner wall—the **intine** (L). The four mature cells separate from one another and form four pollen grains. In monocotyledons, however, the cleavage of the cytoplasm takes place by two planes at right angles to each other, and not in a tetrahedral manner, as in dicotyledons.

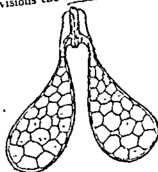


FIG. 243. Pollinia of madar (*Calotropis*).

In bulrush (*Typha*; B. HOGLA; H. PATER).

rush (*Juncus*), sundew (*Drosera*) and a few other cases, the four cells formed in a group do not separate, but remain more or less coherent. In madar (*Calotropis*) and orchids the pollen cells of each pollen-sac instead of separating into loose pollen grains are united into a mass known as the pollinium (fig. 248).

Attachment of the Filament to the Anther (figs. 249-53). There are four principal ways in which the filament is attached to the anther. The anther is said to be (1) **basifixed or innate**, when the filament is attached to the base of the anther, as in mustard, radish, sedge, water lily, etc.; (2) **adnate**, when the filament runs up the whole length of the anther from the base

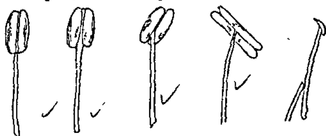


FIG. 249 FIG. 250 FIG. 251 FIG. 252 FIG. 253

Attachment of the filament to the anther. FIG. 249 Basifixed or innate. Fig. 250. Adnate. Fig. 251 Dorsifixed. Fig. 252. Versatile. Fig. 253 Elongated connective of sage (*Salvia*) separating the two anther-lobes (upper one fertile and lower one sterile).

to the apex, as in *Michelia, Magnolia*, etc.; (3) **dorsifixed**, when it is attached to the back of the anther, as in passion-flower; and (4) **versatile**, when it is attached to the back of the anther at a point only so that the latter can swing freely in the air, as in grasses, palms, spider lily (*Pancratium*), etc. In sage (*Salvia*; fig. 253) the filament is attached to the elongated connective separating the two anther-lobes, of which the upper one is fertile and the lower one sterile. The connective plays freely on the filament, and thus when an insect visitor entering the flower pushes the lower lobe the connective *swings round with the result that the upper fertile lobe strikes* the back of the insect and dusts it with pollen grains.

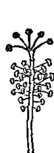
[illegible] rms 'adhesion', 'adnate', and 'adherent' [illegible] embers of different whorls, e.g. petals [illegible] pels; and 'cohesion', 'connate', and [illegible] embers of the same whorl, e.g. stamens with each other, and carpels with each other.

Cohesion of Stamens. Stamens may either remain free or they may be united (coherent). There may be different degrees of cohesion of stamens, and these may be referred to (*a*) adelphous condition when the stamens are united by their filaments only, the anthers remaining free; (*b*) syngenesious

condition when the stamens are united by their anthers only, the filaments remaining free; or (c) synandrous condition when the stamens are united by both the filaments and the anthers. Accordingly the following types are to be noted:

1. **Monadelphous Stamens** (*monos*, single; *adelphous*, bundle). When all the filaments are united together into a single bundle but the anthers are free, the stamens are said to be monadelphous (fig. 254), as in China rose family or *Malvaceae*, e.g. China rose, lady's finger, cotton, etc. In them the filaments are united into a tubular structure, called staminal tube, ending in free anthers.

2. **Diadelphous Stamens** (*di*, two). When the filaments are united into two bundles, the anthers remaining free, the stamens are said to be diadelphous (fig. 255), as in pea family



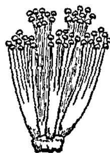



Fig. 254 Fig. 255 Fig. 256 Fig. 257
Cohesion of Stamens. Fig. 254. Monadelphous. Fig. 255. Diadelphous. Fig. 256. Polyadelphous. Fig. 257. Syngenesious.

or *Papilionaceae*, e.g. pea, bean, gram, butterfly pea, coral tree, rattlewort, etc. In them there are altogether ten stamens of which nine are united into one bundle and the tenth one is free.

3. **Polyadelphous Stamens** (*poly*, many). When the filaments are united into a number of bundles—more than two, but the anthers are free, the stamens are said to be polyadelphous (fig. 256), as in silk cotton tree, castor, lemon, shaddock, etc.

4. **Syngenesious Stamens** (*syn*, together or united; *genes*, to form). When the anthers are united together into a bundle or tube, but the filaments are free, the stamens are said to be syngenesious (fig. 257), as in sunflower family or *Compositae*, e.g. sunflower, marigold, safflower, *Tridax*, etc.

[illegible] are united [illegible]

as in gourd family or *Cucurbitaceae*, e.g. ash or wax gourd, sweet gourd, bottle gourd, cucumber, melon, etc. In them there are normally five stamens out of which four are fused in pairs and the odd one remains free. Synandrous stamens are also found in *Araceae*, e.g. taro (*Colocasia*; B KACHU; H. & P. KACHALU), *Alocasia* (B. MAN-KACHU; H. MAN-KANDA), etc.

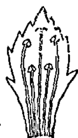




FIG. 258 FIG. 259
Synandrous stamens. Fig. 258. Ash or wax gourd. Fig. 259. Taro.

Adhesion of Stamens. When the stamens adhere to the corolla wholly or partially by their filaments, anthers remaining free, they are said to be (1) **epipetalous**, as in *Datura*, tobacco, potato, *Ixora* (B. RANGAN; H. GOTAGANDHAL), sunflower, etc. and when they are attached to the perianth in the same way, they are said to be **epiphyllous**, as in lily family or *Liliaceae*, e.g. onion, *Asparagus* (B. SATAMULI; H. & P. SATAWAR), etc. Most of the flowers with a gamopetalous corolla have epipetalous stamens. When the stamens adhere to the carpels, either throughout their whole length or by their anthers only, they are said to be (2) **gynandrous**, as in madar (*Calotropis*; B. AKANDA; H. & P. AK), orchids, Indian birthwort (*Aristolochia indica*; B. ISHER-MUL) and pelican flower (*Aristolochia gigas*).

Length of Stamens (figs. 260-1). The stamens of a flower may be of the same length, or their lengths may vary without any definite relation to each other. But in some cases there is a definite relation between short and long stamens. Thus in *Labiatae*, e.g. sacred basil (*Ocimum*; B. & H. TULSI), *Leonurus* (B. DRONA; H. HALKUSHA OR GUMA), *Leucas* (B. SWET-DRONA; H. CHOTA-HALKUSHA), etc., there are four stamens, of which two are long and two short; such stamens are said to be (1) **didynamous** (*di*, two; *dynamis*, strength).



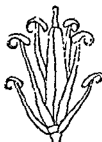


FIG. 260 FIG. 261
Length of Stamens. Fig. 260 Didynamous. Fig. 261. Tetradynamous.

In *Cruciferae*, e.g. mustard, radish, turnip, rape, etc., there are six stamens, of which four are long and two short;

stamens are said to be (2) **tetradynamous** (*tetra*, four). Sometimes different kinds of flowers, some with longer stamens and others with shorter stamens, are borne by the same plant (*dimorphic* stamens). The relative length of stamens with respect to the corolla may be of two types: (1) stamens may be shorter than the tube of the corolla, remaining included within it, when they are said to be **inserted**; and (2) when they are longer, protruding outwards, they are said to be **exserted**.

Number of Stamens. The number of stamens in flowers of different families is variable—1-∞. We find 1 stamen in ginger family and ∞ stamens in cacti. Usually there is a definite number (less than 10) in gamopetalous flowers (advanced types), and an indefinite number (more than 10) in polypetalous flowers (primitive types). As a general rule monocotyledonous flowers have 3 stamens or any multiple of 3, and dicotyledonous flowers have 5 stamens or any multiple of 5.

Insertion or Position of Stamens. Stamens are inserted on the thalamus between the corolla and the gynoecium, but depending on their apparent positions with respect to the ovary they may be hypogynous, perigynous or epigynous (see pp. 108-9).

Dehiscence of the Anther. When the pollen grains mature they exert some pressure from within on the wall of the anther; the latter bursts and sets free the pollen grains. This bursting or dehiscence of the anther takes place in four different ways. The dehiscence is said to be (1) **longitudinal**, when the anther-lobes burst in a longitudinal direction, as in *Datura*, custard-apple, sunflower, China rose, cotton, etc.; (2) **transverse**, when the anther-lobes dehisce breadthwise, as in basil, sacred basil, etc.; (3) **porous**, when dehiscence is effected by one or more apical pores, as in potato, brinjal, etc.; and (4) **valvular**, when it takes place by one or more valves which, like the shutter of a window, open on the outer side only, as in cinnamon, camphor, bay leaf (B. TEZPATA; H. TEZPAT) and barberry.

Appendages of Stamens. Both filaments and anthers may have outgrowths or appendages in the form of hairs, scales, etc. Thus in *Osbeckia* anthers are beaked, while in oleander these are provided with long hairy appendages twisted together into a cone over the stigma (see fig. 238). Similarly, filaments may have appendages. When these are in the form of a regular whorl they form the **staminal corona**. Thus in madar (*Calotropis*) the filaments form a whorl of horn-like corona. In spiderwort (*Tradescantia*) there is a circle of hairs. In spider lily (*Pancratium*; see fig. 602), eucharis lily (*Eucharis*) the corona is formed as a membranous cup adherent to the filaments at their base.

(4) GYNOECIUM OR PISTIL

Gynoecium (*gyne*, female) or **pistil** (*pistillum*, a pestle: the pistil has more or less the shape of a pestle) is the fourth

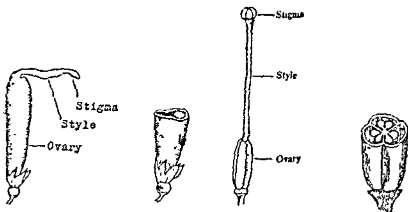


FIG. 262 FIG. 263 FIG. 264 FIG. 265
Pistil. Fig 262. Simple pistil of pea Fig. 263. One-chambered ovary of simple pistil Fig. 264. Syncarpous pistil. Fig. 265. Three-chambered ovary of syncarpous pistil. Note the ovules.

or the female reproductive whorl of the flower, and is composed of one or more carpels which are modified leaves meant to bear female spores or megaspores (embryo-sacs); such megaspore-bearing leaves are otherwise called megasporophylls. When the pistil is made of only one carpel, as in the flowers of pea, bean, gold mohur, sensitive plant, etc., it (the pistil) is said to be **simple or monocarpellary** (figs. 262-3), and when it is made of two or more carpels, the pistil is said to be **compound** or polycarpellary. In a compound pistil the carpels may be free, as in rose, lotus, stonecrop (*Sedum*—a pot herb), *Michelia*

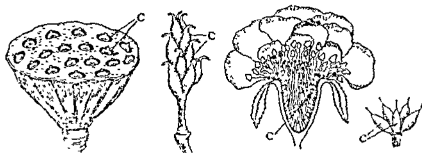
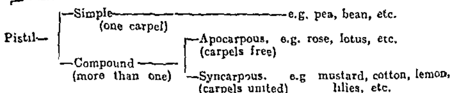


FIG. 266 FIG. 267 FIG. 268 FIG 269
Apocarpous Pistil. Fig. 266. Lotus. Fig 267. *Michelia*. Fig. 268. Rose. Fig. 269. Stonecrop (*Sedum*). *C*, carpels.

(B. CHAMPA; H. CHAMPAK), *Magnolia* (B. DULEE-CHAMPA), *Artabotrys* (B. & H. KANTALI-CHAMPA), *Unona* (B. LAVENDER-

CHAMPA), etc., when the pistil is said to be **apocarpous** (*apo*, off or free ; *karpos*, fruit or ovary ; figs. 266-9), or all the carpels may be united together, as is more commonly found, when the pistil is said to be **syncarpous** (*syn*, together or united ; figs. 264-5). Each pistil consists of three parts—**stigma, style** and **ovary** (fig. 264). The small rounded head of the pistil is known as the **stigma** ; the slender stalk supporting the stigma is called the **style** ; and the swollen basal part of the pistil which forms one or more chambers is termed the **ovary.** The ovary contains one or more little, roundish or oval, egg-like bodies which are the rudiments of seeds and are known as the **ovules.** Each ovule encloses a large oval cell known as the **embryo-sac** (see fig. 286). The ovary gives rise to the fruit and the ovules to the seeds. The apocarpous pistil gives rise to numerous fruits—as many as the number of free carpels ; while the syncarpous pistil gives rise to a single fruit because all the carpels are in this case united together forming only one ovary. When in a pistil the stigma is absent or abnormal, or the ovary does not bear the ovules, or the latter contain no embryo-sac or egg-cell, it (the pistil) is said to be *sterile* ; a sterile pistil is otherwise known as the **pistillode,** as the ray floret of sunflower.



Carpels in Syncarpous Pistil. In a syncarpous pistil it is often difficult to determine the number of carpels. To obviate this difficulty the following points should be noted: 1st, the number of stigmas or of stigmatic lobes ; 2nd, the number of styles ; 3rd, the number of lobes of the ovary ; 4th, the number of chambers (loculi) of the ovary ; 5th, the number of placentae in the ovary ; and 6th, the number of groups of ovules in the ovary. It is seen that in most cases the number of parts, as mentioned above, corresponds to the number of carpels making up the syncarpous pistil.

The Ovary. The carpel is a metamorphosed leaf. The foliar nature of the carpel may be made out from the flowers of pea, bean, gram, etc., where a single carpel is present. *In* such cases the carpel or the pod may be compared to a leaf

which has been folded along its mid-rib (fig. 270). In a folded carpel when the two margins meet and fuse together a chamber is formed, the junction of the fused margins of the carpel

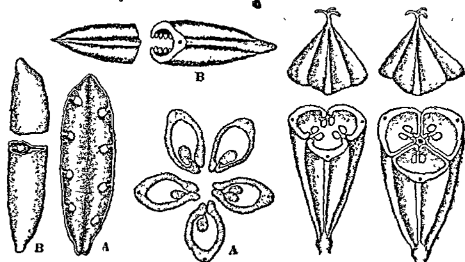


FIG. 270 FIG 271 FIG 272 FIG. 273

Development of the Ovary. Fig. 270. *A*, a single carpel opened out with the ovules on the margins; *B*, one-chambered ovary formed by the folding of the carpel with ovules at the ventral suture. Fig. 271. *A*, one-chambered ovaries formed by five free carpels of an apocarpous pistil; *B*, one of the five ovaries (carpels). Fig. 272. One-chambered ovary formed by the union of margins of three carpels of a syncarpous pistil. Fig 273. Three-chambered ovary formed by the infolding of three carpels and their margins meeting at the centre.

being known as the *ventral suture*, and the mid-rib along which the carpel is folded being known as the *dorsal suture*. Along the ventral suture a ridge of tissue, called **placenta**, develops and bears the ovules in two rows corresponding to the two margins of the carpel. The closed chamber formed by the folding of the carpel, enclosing the ovules, is the **ovary**. When the carpel is closed a projection is formed by apical growth and this differentiates into the **style** and the **stigma**. In apocarpous pistil, as in monk's hood (*Ranunculus*), the ovary is also formed in the above way (fig. 271). In syncarpous pistil, however, the carpels may be united by their margins only, thus forming one-chambered ovary, as in orchids (fig. 272), or, the carpels may be folded inwards, their margins meeting in the centre, thus resulting in a many-chambered ovary with a central axis (fig. 273), as in lily, China rose, etc. Sometimes false partition walls are responsible for more chambers of the ovary than the number of carpels, as in *Datura* (see fig. 788). In gymnosperms, however, the carpels are not closed up to form the ovary and, therefore, there is no stigma, style or ovary. In

them the ovules are borne, freely exposed, along the margins of open carpels (see figs. 698-9).

The Style. The style is the slender projection of the ovary usually developing from its top (fig. 264). Rarely the style is absent, as in buttercup. When the style lies in the same straight line with the ovary, as is normally the case, it is said to be **terminal** or **apical.** Sometimes, however, as in strawberry, the apex of the ovary is turned on one side so that the style is seen to arise from the side of the ovary; it is then termed **lateral.** In basil family or *Labiatae*, e.g sacred basil, *Leonurus*, *Leucas*, etc., and in heliotrope (*Heliotropium* ; B. HATISUR ; H. HATTASURA; P. UNTH-CHARA) the ovary is four-lobed, and the style arises from the depression in the centre of the ovary, as if from its base or directly from the thalamus; the style of this nature is described as **gynobasic** (fig. 274). In a few cases, as in *Canna* and *Iris*, the style becomes flattened and coloured ; it is then said to be **petaloid.** Generally the style is **deciduous,** drying up and falling off soon after fertilization. But in traveller's joy (*Naravelia* ; B. CHHAGAL-BATI) and virgin's bower (*Clematis*; H. BELKUN), etc., the style is **persistent.** The surface of the style may be smooth or bearded, i.e. covered with hairs. In many cases these hairs collect the pollen grains.

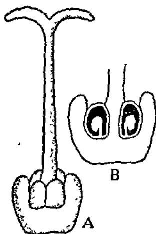


FIG 274. Gynobasic style of basil (*Ocimum*) *A*, entire gynoecium on thalamus ; *B*, the same in longitudinal section Note the disk.

The Stigma. The stigma is the terminal end of the style upon which the pollen grains fall, and is generally knob-like, or sometimes slightly pointed. It may also become flattened or elongated. Generally in the compound pistil it becomes lobed, the number of lobes corresponding to the number of carpels. Not infrequently it is seen to be divided into radiating rays. The surface of the stigma may be smooth or rough, but when it matures it becomes sticky, and the pollen grains adhere to it. In many cases it is hairy or feathery to catch the pollen grains passing on the wind.

Cohesion of Carpels. The carpels may be united either throughout their whole length, as in most syncarpous pistils ; or, they may be united in the region of the ovary alone, styles and stigmas remaining free, as in pink (*Dianthus*), linseed

(*Linum*) and *Plumbago* (B. CHITA ; H. & P. CHITRAK) ; or in the region of the ovary and the style, stigmas remaining free, as in cotton and China rose ; or in the region of the style and

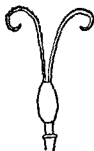
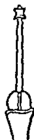





FIG. 275 FIG 276 FIG. 277 FIG. 278

Cohesion of Carpels. Fig. 275. Pistil of China rose with free stigmas. Fig. 276. The same of pink with free styles Fig 277. The same of oleander with free ovaries. Fig. 278. The same of madar with free ovaries and styles

the stigma, ovaries only remaining free, as in periwinkle (*Vinca*), oleander (*Nerium*) ; or in the region of the stigma (and the style partly), as in madar (*Calotropis*).

PLACENTATION

The **placenta** is a ridge of tissue—a parenchymatous outgrowth—in the inner wall of the ovary to which the ovule or ovules remain attached. The placentae most frequently develop on the margins of carpels, either along their whole line of union, called the **suture,** or at their base or apex. The manner in which the placentae are distributed in the cavity of the ovary is known as **placentation.** As a rule the origin of an ovule or a group of ovules determines the position of the placenta.

Types of Placentation (figs. 279-85). In the simple ovary (of one carpel) there is one common type of placentation, known as **marginal,** and in the compound ovary (of two or more carpels united together) placentation may be **axile, parietal, central, free-central, basal, or superficial.**

1. **Marginal.** In marginal placentation (fig. 279) the ovary is one-chambered and the placenta develops along the junction of the two margins of the carpel, called the *ventral suture,* as in *Leguminosae* (e g. pea, gram, gold mohur, *Cassia,* sensitive plant, etc.). The line, or suture, corresponding to the mid-rib of the carpel, is known as the *dorsal suture.* No placenta develops here.

2. **Axile.** In the axile placentation (fig. 280) the ovary is many-chambered—usually as many as the number of carpels—and the placentae bearing the ovules develop from the central axis corresponding to the confluent margins of carpels, and hence the name axile (lying in the axis), as in lemon, orange, China rose, tomato, potato, etc.

In this case the carpels are folded inwards, and their margins meet and fuse together in the centre of the ovary, thus giving rise to a column or axis, and at the same time dividing the ovary into as many chambers (loculi) as there are carpels Sometimes, however, false partition walls are responsible for an increased number of loculi; as, for instances, in thorn-apple (*Datura*; see fig 788E) and tomato (see fig. 316B) there are two carpels, but usually four loculi in the ovary.

Fig. 279 Fig. 280 Fig. 281

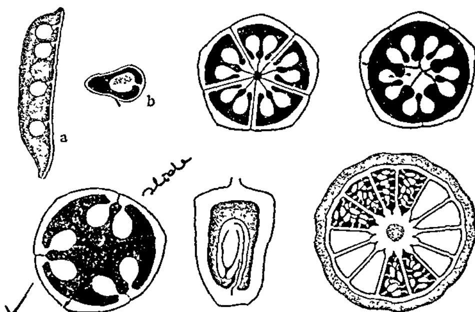


Fig 282 Fig. 283 Fig. 284

Types of Placentation. Fig. 279. Marginal; *a*, longitudinal section; *b*, transverse section. Fig. 280. Axile. Fig. 281. Central. Fig. 282. Parietal Fig. 283. Basal. Fig. 284. Superficial.

3. **Parietal** (*parietis*, wall). In the parietal placentation (fig. 282) the ovary is one-chambered, and the placentae bearing the ovules develop on the inner wall of the ovary. Their position corresponds to the confluent margins of carpels, and their number corresponds to the number of carpels, as in papaw, poppy, prickly poppy, mustard, orchids, etc.

4. **Central.** In the central placentation (fig. 281) the septa or partition walls in the young ovary soon break down so that the ovary becomes one-chambered and the placentae bear-

ing the ovules develop all round the central axis, as in pink family, e.g. pink (*Dianthus*), *Polycarpon* (B. GIMA-SAK), soapwort (*Saponaria*; B. SABUNI; H. MUSNA), *Stellaria*, etc. Remnants of partition walls may often be seen in the mature ovary.

5. **Free-central.** In the free-central placentation (fig. 285) the placenta arises from the base of the ovary, projects far into its cavity as a swollen central axis and bears the ovules all over its surface. Since the placenta lies free in the single chamber of the ovary, the placentation is said to be free-central. This is seen in primrose (*Primula*).

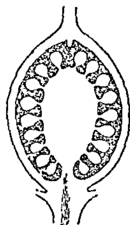
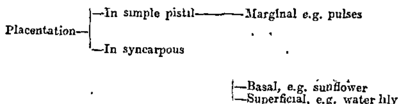


Fig. 285. Free-central placentation of primrose.

6. **Basal.** In the basal placentation (fig. 283) the ovary is unilocular and the placenta develops directly on the thalamus, and bears a single ovule at the base of the ovary. This is seen in sunflower family or *Compositae* e.g. sunflower, marigold, etc.

7. **Superficial.** In the superficial placentation (fig. 284) the ovary is multilocular, carpels being numerous, as in the axile placentation, but the placentae in this case develop all round the inner surface of the partition walls, as in water lily.



THE OVULE

Structure of the Ovule. Each ovule (fig. 286) is attached to the placenta by a slender stalk known as (1) the **funicle.** The point of attachment of the body of the ovule to its stalk or funicle is known as (2) **hilum.** In the inverted ovule, as shown in fig. 286, the funicle continues beyond the hilum alongside the body of the ovule forming a sort of ridge; this ridge is called (3) the **raphe.** The upper end of the raphe which is the junction of the integuments and the nucellus is called (4) the **chalaza.** The main body of the ovule is called (5) the **nucellus,** and it is surrounded by *two* coats, termed

(6) the **integuments.** In gymnosperms, *Compositae* and a few other families with gamopetalous corolla there is only *one* integument. *In parasites* like sandalwood (*Santalum*) and *Loranthus* there is no integument. A small opening is left at the apex of the integuments; this is called (7) the **micropyle.** Lastly, there is a large, oval cell lying embedded in the nucellus towards the micropylar end; this is (8) the **embryo-sac,** *that is,* the sac that bears the embryo, and is the most important part of the ovule.

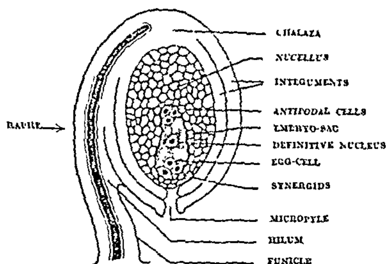


FIG. 286. Ovule in longitudinal section.

Development and Structure of the Embryo-sac. The *embryo-sac* (fig.286) develops in the following way (fig. 287). The ovule at first arises as a tiny protuberance from the placenta in the cavity of the ovary (A). In it even at a very early stage a cell—mother-cell of the embryo-sac—becomes evident in the nucellus (B). This mother-cell increases in size and *divides twice* to form a row of four megaspores, known as the linear tetrad (C). It is to be noted that of the two successive divisions of the mother-cell the first one only is the reduction division (see fig. 386). Of the four cells, so formed, each with half (n) the usual number ($2n$) of chromosomes, the three upper ones degenerate and appear as *dark caps,* while *the lowest one* functions (D). The nucleus of this cell divides and the two daughter nuclei move to the two poles (E). These again divide so that the number is increased to four (F). Each of these nuclei divides again so that altogether eight nuclei are formed in the embryo-sac, four at *each end* (G). The embryo-sac increases in size. Then one nucleus from each

end or pole passes inwards, and the two polar nuclei fuse together somewhere in the middle, forming the **definitive nucleus** (H). The remaining three nuclei at the micropylar end,

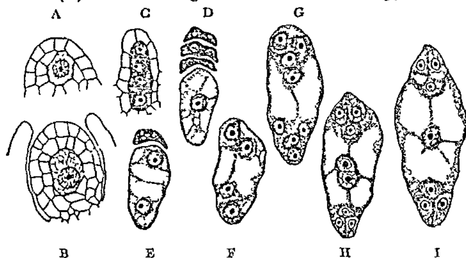
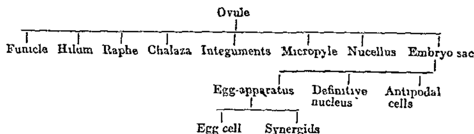


FIG. 287. Development of the embryo-sac. *A, B, C*, etc., are stages in its development; *I*, fully developed embryo-sac.

each surrounded by a very thin wall, form the **egg-apparatus,** and the other three at the opposite or chalazal end, lying in a group or sometimes in a row, often surrounded by very thin walls, form the **antipodal cells** (I).

Of the three cells constituting (1) the **egg-apparatus,** one is the female gamete known as (*a*) the **egg-cell** (or **ovum** or **oosphere),** and the other two are known as (*b*) the **synergids** (co-operating cells; *syn*, together; *ergon*, work) or help cells. Synergids are more or less pear-shaped, and the egg-cell which is enlarged, lies below them. The egg-cells on fertilization gives rise to the embryo; while the synergids aid in the process of fertilization by guiding the pollen tube and as soon as their function is over they get disorganized. The **antipodal cells** have no function; so sooner or later they get disorganized. The **definitive nucleus**(fig. 286) on fertilization (now called the **endosperm nucleus)** gives rise to the endosperm.



Forms of Ovules. The ovule is said to be (1) **orthotropous** (*orthos*, straight; *tropos*, a turn) or **straight**, when the ovule is erect or straight so that the funicle, chalaza and micropyle lie in one and the same vertical line, as in *Polygonaceae*, e.g. *Polygonum* (B. PANI-MARICH; P. NARRI), sorrel (*Rumex*; B. CHUKA-PALANG; H. KHATTA-PALAK; P. KHATTA-MITHA), etc. and in *Piperaceae*, e.g. betel (*Piper betle*). *Piper chaba* (B. CHAI;

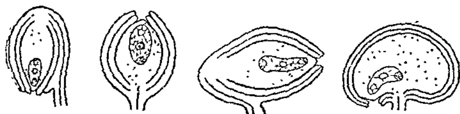


FIG. 288 FIG. 289 FIG. 290 FIG. 291
Forms of Ovules. Fig. 288. Anatropous Fig. 289. Orthotropous. Fig. 290. Amphitropous. Fig 291 Campylotropous.

H. CHAB), long pepper (*Piper longum*; B. PIPOOL; H. PIPLI), black pepper (*Piper nigrum*; B. GOL-MARICH; H. GOL-MIRCH); (2) **anatropous** (*ana*, backwards or up) or **inverted**, when the ovule bends along the funicle so that the micropyle lies close to the hilum; the micropyle and the chalaza, but not the funicle, lie in the same straight line; this is the commonest form of ovule; (3) **amphitropous** (*amphi*, on both sides) or **transverse** when the ovule is placed transversely at a right angle to its stalk or funicle, as in duckweed (*Lemna*); and (4) **campylotropous** (*kampylos*, curved) or **curved**, when the transverse ovule is bent round like a horse-shoe so that the micropyle and the chalaza do not lie in the same straight line, as in gram, bean, *Capparis*, mustard family or *Cruciferae*, four o'clock plant (*Mirabilis*), *Polycarpon* (B. GIMA-SAK), etc.

Position of the Ovule within the Ovary. An ovule may be (1) **ascending**, i.e. directed upwards, as in sunflower family or *Compositae* and basil family or *Labiatae*, (2) **pendulous**, i.e. turned downwards from the apex, as in *Euphorbia*, *Anemone*, coriander, anise, rose, etc.; (3) **suspended**, i.e. turned obliquely downwards from the side; and (4) **horizontal**, i.e. turned horizontally inwards from the side.

CHAPTER IX

POLLINATION

Pollination is the transference of pollen grains from the anther of a flower to the stigma of the same flower or of another flower of the same or sometimes allied species. When

the anther bursts, the pollen grains become scattered; some of them are carried over to the stigma by various agencies such as wind, insects etc. Pollination is of two kinds, viz., (1) **self-pollination or autogamy** (*auto*, self; *gamos*, marriage) and (2) **cross-pollination or allogamy** (*allos*, different). Self-pollination is the transference of pollen grains from the anther of a flower to the stigma of the same flower, evidently bisexual. The term is also applied to the conveyance of pollen grains from a flower (male or bisexual) to a flower (female or another bisexual), both borne by the same individual plant. In self-pollination only one parent plant is concerned to give rise to the offspring. Cross-pollination on the other hand is the transference of pollen grains from one flower to another flower borne by two separate plants of the same or allied species, irrespective of whether the flowers are bisexual or unisexual. In cross-pollination two parent plants are concerned and, therefore, a mingling of two sets of parental characters takes place resulting in better offspring. Both the methods are, however, widespread in nature. After pollination is over the stamens and petals dry up and fall off; the calyx may likewise drop or it may be persistent in the fruit. The stigma dries up after fertilization.

I. Self-pollination or Autogamy

This may take place in bisexual flowers, or in unisexual flowers borne by one and the same plant. In many bisexual flowers, however, there are often certain devices which wholly or partially hinder self-pollination at least in the same flower, while these favour cross-pollination. Even then under natural conditions self-pollination is fairly common in many species. It is, however, wholly prevented in unisexual flowers borne by two separate plants, and also in many bisexual flowers. In the normally self-pollinated species occasional cross-pollination in some generation is a biological necessity to maintain the vigour of the offspring. The following adaptations are commonly met with in flowers to achieve self-pollination.

1. **Homogamy** (*homos*, the same). This is the condition in which the anthers and the stigmas of a *bisexual* flower mature at the same time. (*a*) Under this condition some of the pollen grains may reach the stigma of the same flower through the agency of insects or wind, thus effecting self-pollination. (*b*) The filaments may recoil and bring the mature anthers close to the stigma, as in four o'clock plant (*Mirabilis*). The anthers then burst and discharge their pollen right on

the surface of the stigma. The reverse is also true in some cases, i.e. the stigmas move back and touch the anthers to achieve self-pollination when cross-pollination fails, as in sunflower family or *Compositae* and China rose family or *Malvaceae*. (c) In certain drooping flowers the style may be longer than the filaments, while in certain erect flowers the reverse may be the case. (e) Sessile or almost sessile anthers may lie at the mouth of the narrow corolla-tube and the stigma while pushing out through the tube, brushes against them (anthers), as in *Ixora* (B. RANGAN; H. GOTAGANDHAL), cape jasmine (*Gardenia*; B. GANDHARAJ), periwinkle (*Vinca*; B. NAYANTARA; H. SADABAHAR), etc.

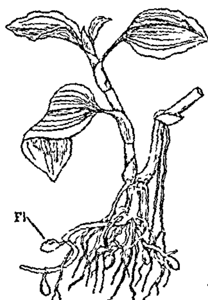


FIG. 292. *Commelina bengalensis*. *Fl*, underground flower.

2. **Cleistogamy** (*kleistos*, closed). There are some bisexual flowers which never open. They are called cleistogamous or closed flowers, and in them the pollen grains are distributed on the stigma of the same flower. Such flowers are very small and inconspicuous. They are never coloured nor do they secrete any nectar; no smell is emitted either. Cleistogamy is seen in the underground flowers of *Commelina bengalensis* (B. KANSHIRA—fig. 292), and also in some species of pansy (*Viola*), balsam (*Impatiens*), sundew (*Drosera*), wood-sorrel (*Oxalis*), etc.

II Cross-pollination or Allogamy

Modes of Cross-pollination. Cross-pollination is brought about by external agents which carry the pollen grains of one flower and deposit them on the stigma of another flower, the two being borne by two separate plants of the same or closely allied species. The agents are insects (bees, flies, moths, etc.), animals (birds, snails, etc.), wind and water. Cross-pollination is the rule in unisexual flowers borne by two separate plants, while in bisexual flowers it is of general occurrence. Nature favours cross-pollination and, therefore, adaptations in flowers to achieve it through external agents are many and varied.

creeper (*Quisqualis*; B. SANDHYA-MALATI; H. LAL-MALTI), etc. Sometimes the smell that is offensive and nauseating to human beings is immensely liked by certain small insects. Thus the appendix of the mature inflorescence of *Amorphophallus* (B. OL; H. KANDA—fig. 293) emits a stinking smell, more offensive than that of putrid meat, and always attracts a swarm of carrion-flies, and pollination is achieved through them.

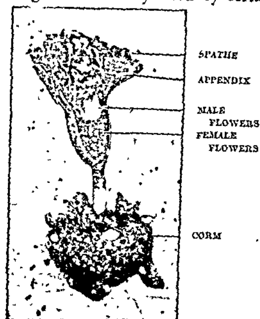


Fig. 293. Spadix of *Amorphophallus campanulatus* (B. OL, H. KANDA).

The pollen grains of entomophilous flowers are either sticky or provided with spinous outgrowths. The stigma is also sticky. Pollen grains and nectar sometimes afford excellent food for certain insects. Flowers commonly attract insects by their colour, nectar or scent; sometimes insects visit the flowers in search of food, or shelter from sun and rain. Thus as they visit the flowers and feed upon the food material (pollen and nectar) their body gets dusted with pollen grains, and when they fly on to other flowers and enter them they brush against the stigma which being sticky at once receives the pollen grains from their body. Thus cross-pollination is brought about.

Special Adaptations

In sunflower, marigold, *Cosmos*, *Anthocephalus* (B., H. & P. KADAM), gum tree (*Acacia*; B. BABLA; H. BABUL; P. KIKAR), etc., where the individual flowers are small and inconspicuous, they are massed together into a dense inflorescence which evidently becomes much more showy and attractive. Dense inflorescence has another advantage; flowers being close together have every chance of being pollinated (see p. 100).

In *Ficus* (e.g. banyan, peepul, fig, etc.) the insects enter the chamber of the inflorescence through the apical pore, and as

they crawl over the unisexual flowers inside the chamber they bring about pollination (fig. 294). Female flowers lie at the base of the cavity and open earlier, while male flowers lie near the apical opening and open later so that pollen grains have to be brought over from another inflorescence.

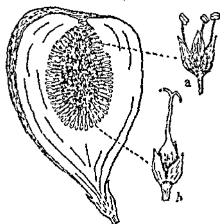


Fig. 294. Fig (*Ficus*) cut lengthwise. Note the apical opening guarded by scales. *a*, male flower, *b*, female flower.

Flowers are often adapted for pollination by a definite type of insects; others are useless in this respect. For instance, in snapdragon (see fig. 230) and other flowers having personate corolla, only the insects of particular size and weight can open the mouth of the corolla. Again long-tongued insects are only useful in the case of the flowers with long corolla-tube.

A very interesting case of cross-pollination by insects is seen in sage (*Salvia*; B. BHUI-TULSI, P. TUKH-MALANGA—fig. 295). There are two stamens in the flower, with the two anther lobes of each widely separated by the elongated curved connective which plays freely on the filament. The upper lobe is fertile and the lower one sterile. In the natural position the connective is upright. When the insect enters the tube of the corolla it pushes the lower *sterile* anther lobe of each stamen; the connective swings round with the result that the upper fertile lobe comes down and strikes the back of the insect and dusts it with pollen grains. The flower is protandrous, and when the stigma matures it bends down and touches the back of the insect and receives the pollen grains therefrom. Thus pollination is brought about. This is a special mechanism for cross-pollination.

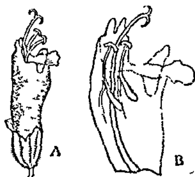


Fig. 295. Sage (*Salvia*). *A*, entire flower; *B*, showing elongated connective.

2. **Anemophily** (*anemos*, wind). In some cases pollination is brought about by wind. Anemophilous or wind-loving

flowers are small and inconspicuous. They are never coloured or showy. They do not emit any smell nor do they secrete any nectar. The anthers produce an immense qunatity of pollen grains, wastage during transit from one flower to another being considerable. They are also light and dry; sometimes, as in pine, these are provided with wings for facility of distribution by wind. Stigmas are comparatively large and *protruding, sometimes branched and* often feathery. Examples are afforded by grasses, bamboos, cereals, millets, sugarcanes, sedges, pines, and several palms. Anemophily is well illustrated by maize or Indian corn plant (fig. 296). The plant bears a large number of male flowers (spikelets) in a terminal panicle, and lower down it bears 1 or 2 female spadices, each in the axil of a leaf, surrounded by spathes. A cluster of fine, long and silky threads —the styles—are seen to hang in tufts from the spadix. When the anthers burst a cloud of dust-like pollen grains is seen floating in the air close round the plant. Some of these floating pollen grains are caught by the protruding stigmas. and thus pollination is effected. By far the greater majority of pollen grains are, however, blown away and wasted. *In gunpowder plant (Pilea)* the anthers explode and puffs of pollen grains are ejected from them and blown about by wind.

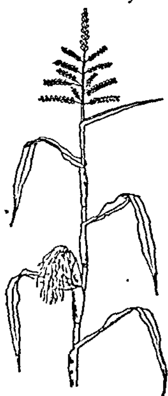


FIG. 296. Maize plant with male flowers in a panicle (on the top) and female flowers in a spadix (at the bottom). Note the styles dangling in the air.

3. **Hydrophily** (*hydor*, water). Pollination may also be brought about in some aquatic plants, particularly the submerged ones, through the medium of water, e.g. *Naias*, *Vallisneria*, *Hydrilla*, etc. Those aquatic plants that lift their flowers above the water normally achieve pollination through insects or wind. Hydrophily may be illustrated by *Vallisneria* (fig. 297). The mode of pollination in it is as follows. The plant is dioecious and submerged. The male plant bears a large number of very minute male flowers in a small spadix surrounded by a spathe and borne on a short stalk, while the female plant bears solitary female flowers, each on a long

slender stalk. The stalk quickly elongates and lifts the female flower to the surface of the water. The spathe bursts and the male flowers are released from the spadix, while still closed, and float on the surface of the water; the perianth expands giving

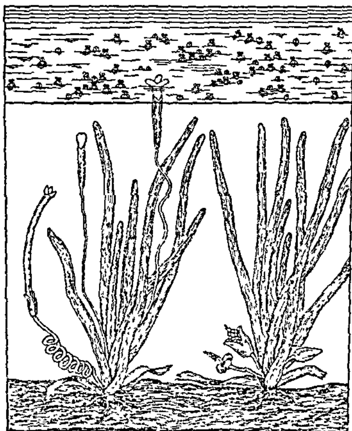


FIG. 297. *Vallisneria.* *Left*, a female plant with a floating female flower, a submerged flower (-bud) and a fruit (6 inches long) maturing under water after pollination; *right*, a male plant with two spadices, each bearing a large number of very minute male flowers covered by a spathe, and also an old spadix from which male flowers have got detached. Note the male flowers (size much enlarged) floating on water.

buoyancy to them. Some of the floating male flowers come in contact with the female flowers. The anthers dehisce, and some of the sticky pollen grains adhere to the margins and surfaces of the tri-fid stigmas which then close up. After pollination the stalk of the female flower becomes spirally coiled and thus pulls the female flower down into the water. The fruit develops and matures under water a little above the bottom. Hydrophilous flowers are as a rule small and inconspicuous.

4. **Zoophily** (*zoon*, animal). Birds, squirrels, bats, snails, etc., also act as useful agents of pollination; for example, birds and squirrels bring about pollination in coral tree (*Erythrina*) and silk cotton tree (*Bombax*); bats in *Anthocephalus* (B. & H. KADAM); and snails in certain large varieties of aroids and in snake plant (*Arisaema*—see fig. 183). (Insects are also instrumental in bringing about pollination in them.) In aroids, otherwise called 'lords and ladies', the inflorescence is a spadix; the female flowers or the 'ladies' lie at the base of the spadix and the male flowers or the 'lords' higher up. The stigmas come to maturity first so that the pollen must be brought from another inflorescence (see fig. 182).

Advantages and Disadvantages of Self- and Cross-pollinations. Self-pollination has this advantage that it is almost certain in a bisexual flower provided that both stamens and carpels of it have matured at the same time Continued self-pollination generation after generation has, however, this disadvantage that it results in weaker progeny. The advantages of cross-pollination are many (a) it always results in much healthier offspring which are better adapte [illegible] (b) more abundant and viable seeds are [illegible] w varieties may also be produced by the [illegible] d (d) the *adaptability of the plants to their environment is better by this method.* The disadvantages of cross-pollination are that the plants have to depend on external agencies for the purpose, and this being so, the process is more or less precarious and also less economical as various devices have to be adapted to attract pollinating agents, and that there is always a considerable *waste of material (pollen) when wind is the pollinating agent.*

Contrivances for Cross-pollination. The contrivances met with in flowers favouring cross-pollination, either wholly or sometimes partially, are many and varied. These are as follows:

1. **Dicliny or Unisexuality.** Diclinous (*di*, two or asunder; *kline*, a bed) flowers are unisexual, i.e. stamens and carpels lie in separate flowers—male and female, either borne by the same plant or by two separate plants. It is thus evident that there are two cases of dicliny: (*a*) when the male and the female flowers are borne by one and the same plant, *it* (*the plant*) *is* said to be **monoecious** (*monos*, single; *oikos*, a house), e.g. gourd, cucumber, castor, maize, etc.; and (*b*) when the male and the female flowers are borne by two separate *plants*, that is, when the male flowers are borne by one plant and the female flowers are borne by another plant, it (the plant) is said *to be* **dioecious** (*di*, two or asunder), e.g. palmyra-palm, papaw, mulberry, etc. In monoecious plants the flowers may be self-pollinated or cross-pollinated, while in dioecious plants cross-pollination is indispensable for the production *of seeds.*

2. **Self-sterility.** This is the condition in which the pollen of a flower has no fertilizing effect on the stigma of the same flower. As a matter of fact it is seen, as in some orchids, that the pollen has an injurious effect on the stigma of the same flower; the stigma, when the pollen is applied to it, dries up and falls off. Tea flowers, some species of passion-flower and Indian mallow (*Malva*), are also self-sterile. Pollen applied from another plant of the same or allied species is only effective in such cases. Cross-pollination is thus the only method in them for the setting of seeds.

3. **Dichogamy** (*dicha,* in two). In many bisexual flowers the anther and the stigma often mature at different times. This condition is known as **dichogamy.** As the anther and the stigma come to maturity at different times, dichogamy often stands as a barrier to self-pollination. There are two conditions of dichogamy: (*a*) **protogyny** (*protos,* first; *gyne,* female) when the gynoecium matures earlier than the anthers of the same flower; here the stigma receives the pollen grains brought from another flower. Common examples are *Ficus* (fig. banyan, peepul, etc.), four o'clock plant, *Magnolia,* custard-apple, some palms, etc.; and (*b*) **protandry** (*protos,* first; *andros,* male) when the anthers mature (burst and discharge their pollen) earlier than the stigma of the same flower; here the pollen grains are carried over to the stigma of another flower. Common examples are *Clerodendron* (fig. 298), China rose, cotton, lady's finger, sunflower, marigold, coriander, *Carum* (B. JOWAN; H. & P. AJOWAN), wood-sorrel, rose, etc. Protandry is more commonly found than protogyny.

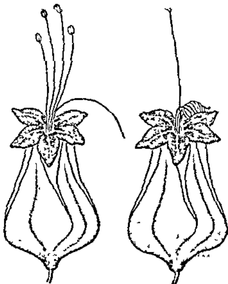
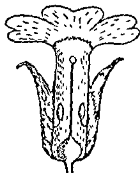


FIG. 298. Protandrous flowers of *Clerodendron*; A, stamens maturing first; *B*, stigma maturing later.

4. **Heterostyly** (*heteros,* different). There are some plants which bear flowers of two different forms. One form bears long stamens and a short style, and the other form bears short stamens and a long style. This is known as *dimorphic*

(*di*, two; *morphe*, form) *heterostyly*. Similarly there may be cases of *trimorphic* heterostyly, that is, stamens and styles of three different lengths borne by three different forms of flowers. In all such cases cross-pollination readily takes place between stamens and styles of the same length borne by different flowers. Self-pollination may sometimes take place between stamens and styles of different lengths borne by the same flower when cross-pollination fails. In red linseed (*Linum*) self-pollination produces absolutely no seed. Dimorphic heterostyly is seen in primrose, buckwheat, wood-sorrel (*Oxalis*), linseed (*Linum*) and *Woodfordia* (B. DHAINPHUL). Trimorphic heterostyly is found in some species of *Oxalis* and *Linum*.



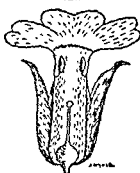


FIG. 299 FIG. 300
Dimorphic flowers of primrose.
Fig. 299. A flower with long style.
Fig. 300. A flower with short style.

5. **Herkogamy** (*herkos*, a fence or barrier). In some homogamous flowers there are often certain adaptations of the floral parts which act as a fence or barrier to self-pollination and thus favour cross-pollination by insects. The two organs may lie at some distance from each other; the anthers may be inserted within the corolla tube and the style exserted, or the anthers exserted and the style inserted, or the anthers may be facing outwards, or these may be sheltered or hooded by the petals or by the petaloid style, as in *Iris*, or the relative position of anthers and stigmas may be such as to prevent self-pollination. Thus we find that the pollinia of orchids and madar (*Calotropis*) develop in a position wherefrom they cannot reach the stigmas by themselves. Besides these remain fixed in their position by adhesive discs, and can only be carried away by insects. The peculiar arrangement of stamens and pistil in sage (*Salvia*) to achieve cross-pollination has been already discussed (see p. 141). In pansy (*Viola tricolor*) the stigma is guarded by a flap or lid which the insect closes as it withdraws from the flower, thus preventing self-pollination by its own pollen.

CHAPTER X

FERTILIZATION

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tive units, calle[illegible]
of fertilization, [illegible]
After pollination, that is, after the pollen grains reach the stigma, the intine of each grows out into a tube, called the **pollen-tube** (see fig. 246), through some thin or weak spots or *germ pores* in the exine (see fig. 245). The growth of the pollen-tube is stimulated by sugary substances secreted by the stigma. The tube penetrates the stigma and pushes its way through the style and the wall of the ovary or alongside it, carrying with it the **tube-nucleus** and the **generative nucleus.** The generative nucleus divides forming two **male gametes,** while the tube-nucleus gets disorganized sooner or later. Sometimes, however, the generative nucleus divides before pollination.

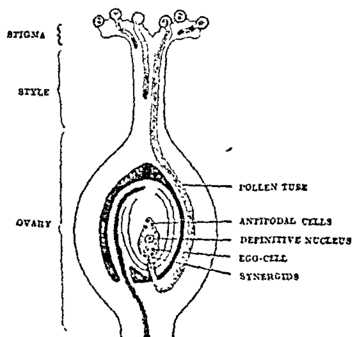


FIG. 301. Ovary in longitudinal section showing the process of fertilization. Note the two male gametes at the tip of the pollen-tube.

A mass of cytoplasm accumulates at the tip of the pollen-tube with the nuclei lying embedded in it. The pollen-tube [illegible] down the wall of the ovary and finally it turns towards

of the ovary. The pollen-tube then passes through the micropyle of the ovule, whatever be its position in the cavity of the ovary. The pollen-tube then passes through the micropyle and at length reaches the embryo-sac. This is called porogamic fertilization. Sometimes, however, as in beef-wood tree (*Casuarina*; B. & H. JHAU) and some other plants, the pollen-tube enters the embryo-sac through the base (chalaza) of the ovule, or even piercing the integuments. This is called chalazogamic fertilization, first discovered in 1891. After the pollen-tube enters the embryo-sac its tip dissolves and the male gametes are set free. Of the two gametes one fuses with the egg-cell, while the other pushes farther into the embryo-sac and fuses with the two polar nuclei or their fusion product, i.e. the **definitive nucleus** Thus fertilization is completed. The fusion of a male gamete with the two polar nuclei is often termed *triple fusion*. In the process of fertilization synergids are supposed to direct the male gametes towards the egg-cell and the definitive nucleus, and as soon as fertilization is over they get disorganized. Antipodal cells have no positive function; so they disappear even before fertilization.[1] After fertilization the egg-cell clothes itself with a cell-wall and becomes known as the **oospore.** The oospore gives rise to the embryo, the ovule to the seed, and the ovary as a whole to the fruit, and the definitive nucleus, now called the **endosperm nucleus,** to the endosperm. If fertilization fails for some reason or other, the ovary simply withers and falls off. In certain cultivated varieties of banana, papaw, orange, grape, apple, pine-apple, etc., the ovary may develop into the fruit without fertilization. The development of the fruit without fertilization is spoken of as **parthenocarpy.** Parthenocarpic fruits rarely contain seeds. The time involved between pollination and fertilization varies a good deal in different plants. Generally the time taken is from a few hours to a few days, but in some cases the time may be extended to a few or even many months—six months or more in meadow saffron and about thirteen months in oak. The time really depends on the rate of growth of the pollen-tube, and not so much on the length of the style. In some gymnosperms fertilization takes place only in the year following pollination. Since one male gamete of a pollen grain fuses with one egg-cell of an ovule, it is evident that as many pollen grains would be required for complete fertilization of the ovary as there are ovules in it. Normally, however, numerous pollen grains are deposited on the stigma, and many of them form pollen-tubes; but only those tubes

[1] Synergids and antipodal cells are generally regarded as vestigial structures, being remnants of the archegonium and the prothallus respectively.

become effective that reach the ovules prior to others; other pollen-tubes simply dry up. The withering and shedding of the corolla usually indicates that fertilization has been effected. This is readily seen in night jasmine (*Nyctanthes*) where the whole ground is seen littered with shed flowers (corollas with epipetalous stamens) in the morning, fertilization having taken place the preceding night.

Double Fertilization. *It must have been noted from the foregoing* description that in angiosperms fertilization occurs twice: (*a*) one of the two male gametes of the pollen-tube fuses with the ovum of the embryo-sac, and (*b*) the other gamete fuses with the definitive nucleus which is the product of [illegible] 'he *development of the embryo-sac.* This [illegible] It was first discovered by Nawaschin in [illegible] amazing discovery attracted great atten- [illegible] established the fact that this double [illegible] nce *among the angiosperms* The *significance* of double fertilization is not clearly understood. The fusion of one of the male gametes with the ovum results in the formation of the embryo; while the fusion of the other male gamete with the definitive nucleus results *in the formation of the endosperm, and not in the formation of a sister* embryo, as expected. It has been suggested that the presence of a second polar nucleus might be a disturbing element, and as such the definitive nucleus (endosperm nucleus) develops, as a result of *triple fusion*, into the *endosperm instead of growing into an embryo.*

Reduction Division. [illegible] process of reduction divisio[illegible] and fig. 287) and, therefore, [illegible] gamete or egg-cell of the [illegible] many chromosomes as the mother cells. Then when these two gametes fuse together the number of chromosomes becomes doubled in the oospore ($n+n=2n$). This is how a constant number of chromosomes is maintained from generation to generation.

CHAPTER XI

THE SEED

Development of the Seed. After fertilization a series of changes takes place in the ovule, and as a result the seed is formed. The fertilized egg-cell or ovum grows and gives rise to the embryo, and the definitive nucleus to the endosperm; other changes also take place in the ovule.

1. **Development of the Embryo** (**Embryogeny**; fig. 302). After fertilization the **egg-cell** or **ovum** secretes a cellulose wall round itself and becomes the **oospore**. The latter divides into two cells—an *upper* and a *lower*. The upper one lying towards the micropyle further divides in one direction into a row of cells, called the **suspensor**. The suspensor, as it elongates, pushes the developing embryo deep into the embryo-sac, and it also acts as a feeding organ to the embryo during the formation

of the latter. For this purpose the terminal cell of the suspensor often enlarges and acts as an absorbing organ. The suspensor,

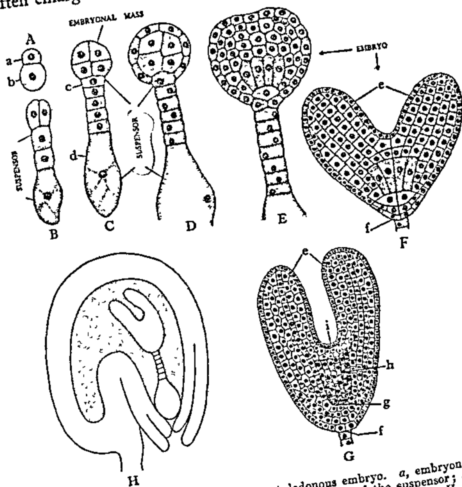


FIG. 302. *A-H*, development of dicotyledonous embryo. *a*, embryonal cell; *b*, suspensor cell; *c*, hypophysis cell; *d*, basal cell of the suspensor; *e*, cotyledons; *f*, root-cap; *g*, root-tip; *h*, hypocotyl; and *i*, stem-apex. *H*, embryo within the seed.

however, gets disorganized as the radicle is formed. The basal cell of the suspensor, called the **hypophysis cell** (*hypo*, below; *phyo*, to grow), divides and gives rise to the apex of the radicle. The lower cell, known as the **embryonal cell**, enlarges and divides by three walls at right angles into eight cells (octants or compartments), four cells lying towards the suspensor forming the posterior octants and the other four cells lying away forming the anterior octants. Each octant then divides by a wall parallel to its curved surface. Thus a surface (superficial) layer of cells and a central mass of cells, the latter being known as the **embryonal mass**, are formed. The surface layer divides

in one direction by radial walls only and remains single-layered; finally it gives rise to the dermatogen, i.e. the outer layer of the stem-apex and the root-apex. The embryonal mass gives rise to the whole of the embryo except the root-tip. The cells of the embryonal mass divide repeatedly and the various parts of the embryo become differentiated. Thus it is seen that the **plumule** and the **two cotyledons** are derived from the anterior octants, and the main part of the **radicle** and the **hypocotyl** from the posterior octants. The apex of the radicle, as already stated above, is derived from the hypophysis cell.

In the dicotyledonous embryo *two* cotyledons are formed, which are laterally placed, and the plumule is *terminal*. In the monocotyledonous embryo, on the other hand, there is only *one* cotyledon formed, which is terminal, and the plumule is *lateral*. Recent researches, however, show that this distinction is not absolute.

2. **Development of the Endosperm.** After the fusion of one of the male gametes with the definitive nucleus (i.e. as a result of *triple fusion*) the latter, now called the endosperm nucleus, begins to grow. It divides and gives rise to a large number of small nuclei (see fig. 387). Protoplasm collects round each of the nuclei, and finally cell-walls are formed between them. A tissue—food storage tissue—is thus formed by a process of free cell formation, which is known as the **endosperm or albumen.** As it grows it fills up the nucellus. In many seeds no endosperm is seen at maturity although it is always formed at the initial stage of embryo development. This is explained by the fact that the embryo, in the process of development, continually draws in the food stored up in the endosperm, and completely exhausts it; so when nothing is left behind the seed becomes **exalbuminous.** In some cases, however, the endosperm grows very vigorously so that the embryo cannot completely exhaust it; the seed is then said to be **albuminous.** In most cases as the endosperm grows it completely fills up the nucellus space so that no nucellus is found in the seed; but in a few cases, as in water lily, ginger family, four o'clock plant and glory of the garden it (the nucellus) persists and grows into a nutritive tissue like the endosperm, called the **perisperm.** The perisperm surrounds the endosperm, while the latter, if and when present, surrounds the embryo, as in water lily, betel, black pepper, cubeb, etc.; the perisperm only without the endosperm is found in ginger family. Both endosperm and perisperm are found

in water lily, ginger family and betel family. The albumen may be *mealy*, when it is filled up with starch grains, as in rice, wheat, etc. ; it may be *oily*, when it contains oil-globules, as in castor and coco-nut ; it is *fleshy*, when it is soft and thick ; it is said to be *mucilaginous*, when its walls are formed of mucilage, a slimy substance ; and it is *horny*, when it becomes very thick and hard, as in vegetable ivory-palm and betel-nut.

3. **Other Changes in the Ovule.** A few other changes also take place in the ovule. The two integuments develop into two **seed-coats,** of which the outer one is called the *testa* and the inner one the *tegmen*. In some seeds there is only one coat of the ovule, and in some parasites no coat is present at all. The funicle gives rise to the stalk, and the hilum, micropyle, raphe and chalaza give rise to the corresponding parts in the seed. In some seeds, as in water lily, nutmeg (B. & H. JAIPHAL), wild mangosteen (B. GAB ; H. KENDU), etc., there is usually found an outgrowth of the funicle, which grows up around the ovule and more or less completely envelops the seed ; an outgrowth of this nature is called an **aril** ; the mace (B. JAITRI) of nutmeg is the aril, and so also is the flesh of litchi and *Baccaurea* (B. LATKAN ; H. LUTKO). In *Pithecolobium* (B. & H. DEKANI-BABUL) also the aril is fleshy and edible. A small outgrowth formed at the micropyle may also be seen in some seeds, as in castor and other *Euphorbiaceae*, balloon vine (B. KAPAL-PHUTKI), etc. ; this is known as the **caruncle** (see fig. 5A). A scar may be seen on one side of the seed ; this scar is known as the **hilum** ; it indicates the point of attachment of the seed or ovule to the stalk or funicle. The various parts met with in the ovule and the seed may now be compared.

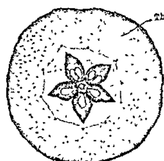
Ovule		Seed
Funicle	...	Stalk
Integuments with hilum, raphe, chalaza and micropyle	...	Seed-coats with corresponding parts
Nucellus	...	Perisperm
Embryo-sac—		
(a) Egg-apparatus :		
(i) Synergids	...	disorganized
(ii) Egg-cell	...	Embryo
(b) Definitive nucleus	...	Endosperm
(c) Antipodal cells	...	disorganized

CHAPTER XII

THE FRUIT

Development of the Fruit. *After fertilization the primary result is the development of the embryo with incidental* changes in the ovule which as a whole becomes converted into the seed. This development of the embryo is associated with a series of changes in the wall of the ovary and often in other parts of the flower connected with fruit formation. These changes result *in the development of the fruit from the ovary.* The fruit may, therefore, be regarded as a mature or ripened ovary. If, for some reason or other, fertilization fails, the ovary simply withers and falls off. A fruit consists of two portions, viz. the **pericarp** (*peri*, around; *karpos*, fruit) developed from the wall of the ovary, and the **seeds** developed from *the ovules. In some cultivated varieties of* oranges, bananas, grapes and other fruits the ovary may grow into the fruit without fertilization. Such a fruit is seedless and known as the **parthenocarpic** fruit. The pericarp may be thick or thin; when thick, it may consist of two or three parts: the outer, called *epicarp*, forms the skin of the fruit; the middle, called *mesocarp*, is pulpy in fruits like mango, peach, palms, etc., and the inner, called *endocarp*, is often very thin and membranous, as in orange, or it may be hard and stony, as in many palms, mango, etc. In many cases, however, the pericarp is not differentiated into these three regions.

When only the ovary of the flower grows into the fruit, it is commonly known as the **true fruit**, but often it is found that other floral parts such as the thalamus, receptacle, or calyx may also grow and form a part of the fruit; such a fruit is known as the **false** or **spurious fruit** or pseudocarp. Thus





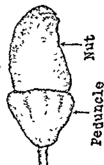


Fig. 303   Fig. 304   Fig. 305

Fig. 303. Apple in transverse section. Fig. 304. Cashew-nut (*Anacardium*). Fig. 305. Marking nut (*Semecarpus*).

in *Dillenia* (B. & H. CHALTA) the calyx is persistent and fleshy forming the prominent part of the fruit. In apple (fig. 303) and pear the thalamus grows round the ovary and becomes fleshy. In strawberry the thalamus swells up bearing a number of small fruits on its outer convex surface. In rose (see fig. 268) the thalamus is enlarged and bears small true fruits on its inner concave surface. In sunflower family the inferior fruit (see fig. 335) is surrounded by the dry thalamus and often crowned by hairs (pappus). In cashew-nut (*Anacardium*; B. HIJLI-BADAM ; H. KAJU—fig. 304) the peduncle and the thalamus grow and become swollen and fleshy forming an edible fruit-like body which is a false fruit or pseudocarp, while the actual fruit which is an edible reniform nut, developing from the ovary, is seated on the swollen peduncle. Similarly in marking nut (*Semecarpus* ; B. BHALA ; H. BHILAWA —fig. 305) the peduncle becomes fleshy with the actual nut seated on its top ; the nut is not edible but it is used by washermen to mark cotton clothes. The aggregate fruit of custard-apple with a number of small true fruits fused together is a spurious one. Lastly, fruits developing from an inflorescence like those of mulberry, pine-apple, jack, fig, banyan, etc., are also regarded as spurious fruits.

Dehiscence of Fruits (fig. 306). There are many fruits whose pericarp bursts to liberate the seeds, when the former mature ; such fruits are said to be **dehiscent.** There are others again whose pericarp does not burst, and consequently the seeds cannot be liberated from the fruits until decay of the latter has set in. Fruits that belong to this category are said to be **indehiscent.** Dehiscent fruits open in various ways, and according to the mode of opening, dehiscence may be **transverse, porous,** and **longitudinal** or **valvular.**

1. **Transverse** (fig. 306C), when the fruit bursts transversely so that the upper part separates away from the lower like the unhinged lid of a box, as in cock's comb (*Celosia*), purslane (*Portulaca*), etc.

2. **Porous** (fig. 306B), when the fruit ruptures by a number of little pores through which the seeds are set free, as in poppy, bath sponge, etc.

3. **Valvular,** when the fruit bursts longitudinally from apex to base or the other way, either partially or completely. When the dehiscence takes place completely the fruit breaks up into a number of pieces, called valves, and hence the name *valvular* dehiscence. It may be of the following kinds:

In Monocarpellary Fruits—

(1) **Sutural** (fig. 306A). When the monocarpellary fruit opens it always does so by sutures, either ventral, as in madar, or dorsal, as in *Magnolia*, or by both, as in *Leguminosae*, e.g. pea, bean, etc., and then dehiscence is said to be sutural.

In Polycarpellary Fruits—

(2) **Loculicidal** (fig. 306D), when the splitting of the fruit takes place through the back of the loculus (or chamber) and

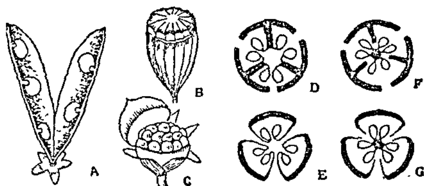


FIG. 306. Dehiscence of fruits. *A*, sutural (pea); *B*, porous (poppy); *C*, transverse (cock's comb); *D*, loculicidal; *E*, septicidal; *F-G*, septifragal.

the valves separate from the axis, as in pink, *Malvaceae*, e.g. cotton, lady's finger, *Hibiscus mutabilis* (B. STHALPADMA; H. GULIAJAIB), etc., and *Acanthaceae*, e.g. *Adhatoda* (B. BASAK; H. ADALSA; P. BASUTI), *Ruellia*, *Andrographis* (B. KALMEGH; H. MAHATITA), etc.

(3) **Septicidal** (fig. 306E), when the dehiscence takes place through the septa, i.e. the partition walls of the fruit so that the latter is seen to split up into its component carpels, as in linseed, devil's cotton (*Abroma*; B. & H. ULAT-KAMBAL), mustard family or *Cruciferae*, e.g. mustard, radish, etc.

(4) **Septifragal** (fig. 306 F-G), when the dehiscence of a multilocular fruit takes place loculicidally or septicidally and at the same time the septa or partition walls break so that the valves fall away leaving the seeds attached to the central axis, as in thorn-apple (*Datura*), toon (*Cedrela*; B. & H. TOON), *Pterospermum* (B. MOOCH-KANDA; H. KANAK-CHAMPA), etc.

CLASSIFICATION OF FRUITS

Fruits, whether true or spurious, may be broadly classified into three groups, viz. **simple**, **aggregate** and **multiple** or **composite**.

A. Simple Fruits

When a single fruit develops from the ovary of a flower with or without accessory parts (true or spurious fruits as explained above), it is said to be a **simple fruit.** A simple fruit may be dry or fleshy. Dry fruits may again be dehiscent or indehiscent or schizocarpic (in which the carpel or carpels split into 1-seeded parts).

I. Dehiscent or Capsular Fruits

1. **Legume or Pod** (fig. 307). This is a dry *monocarpellary* fruit developing from a superior, one-chambered ovary and dehiscing by both the sutures, as in *Leguminosae*, e.g. pea, bean, pulses, rattlewort (B. ATASHI ; H. JHUNJHUNIA), etc.

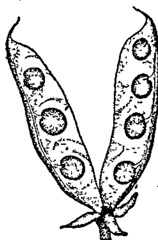


Fig. 307



Fig. 308

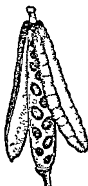


Fig. 309



Fig. 310

Fruits. Fig. 307. Legume or pod of pea. Fig. 308. Follicle of madar (*Calotropis*). Fig. 309. Siliqua of mustard. Fig. 310. Capsule of thorn-apple (*Datura*).

2. **Follicle** (fig. 308). This is also a dry, *monocarpellary*, superior, one-chambered fruit like the previous one, but it dehisces by one suture only, as in madar (*Calotropis*), blood flower (*Asclepias*), periwinkle (*Vinca*), *Michelia*, etc.

3. **Siliqua** (fig. 309). This is a long, narrow, many-seeded fruit developing from a superior, *bicarpellary* ovary with two parietal placentae. It dehisces from below upwards by both the sutures. The ovary is one-chambered at first, but as it grows into the fruit it becomes two-chambered, owing to the development of a false partition wall, called *replum*, which extends from one placenta to the other. Siliqua is found in mustard family or *Cruciferae*, e.g. mustard, radish, etc. When a siliqua is much shorter and flattened, being

nearly as broad as it is long, and contains only a few seeds, as in shepherd's purse (*Capsella*) and candytuft, it is called a **silicula**. A siliqua is long and narrow, while a silicula is short broad and flat.

4. **Capsule** (figs. 310-1). This is a many-seeded, uni- or multilocular fruit developing from a superior (or sometimes inferior), *bi-* or *polycarpellary* ovary, and dehiscing in various ways. All dehiscent fruits developing from a syncarpous ovary are commonly known as capsules. A capsule may dehisce by pores, as in poppy; or transversely, as in cock's comb; or loculicidally, as in cotton, lady's finger and *Hibiscus mutabilis* (B. STHALPADMA; H. & P. GULIAJAIB); or septicidally, as in linseed; or septifragally, as in *Datura*.

II. *Indehiscent or Achenial Fruits*

1. **Caryopsis** (see figs. 6 & 7). This is a very small, dry, one-seeded fruit developing from a superior, *monocarpellary* ovary, with the pericarp fused with the seed-coat. Examples are afforded by grass family or *Graminaceae*.

2. **Achene** (fig. 312). An achene is a small, dry, one-chambered and one-seeded fruit developing from a superior, *monocarpellary* ovary; but unlike the previous one, the pericarp of this fruit is free from the seed-coat. Achenes commonly develop from an apocarpous pistil and, therefore, a single flower produces an aggregate of achenes—as many as there are free carpels in the flower, as in virgin's bower (*Clematis*; H. BELKUN) and traveller's joy (*Naravelia*; B. CHHAGAL-BATI).

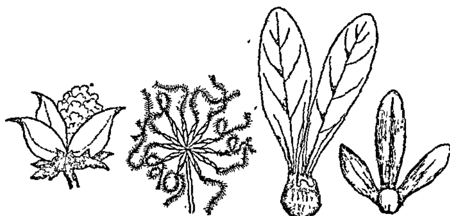


FIG. 311 FIG. 312 FIG. 313 FIG. 314

Fruits (*contd.*). Fig. 311. Capsule of cotton. Fig. 312 Achenes of *Naravelia*. Fig. 313. Samara of *Dipterocarpus*. Fig. 314. Samara of *Hiptage*.

3. **Cypsela** (see fig. 335). This is a dry, one-chambered and one-seeded fruit developing from an inferior, *bicarpellary* ovary with the pericarp and the seed-coat free, as in sunflower family or *Compositae*, e.g. sunflower, marigold, *Cosmos*, etc.

4. **Nut.** This is a dry, one-chambered and one-seeded fruit developing from a superior, *bi-* or *polycarpellary* ovary, *with the pericarp hard and woody*, e.g. chestnut, oak, beech, etc.

Coco-nuts and palmyra-palms are drupes because in them it is the endocarp that becomes hard and woody (and not the whole of the pericarp), and areca- or betel-nuts and date-palms are (one-seeded) berries because in them the pericarp is soft (fibrous in areca-nuts and pulpy in date-palms); it is the seed that is stony (and not the pericarp).

5. **Samara** (figs. 313-4). This is a dry, indehiscent, one- or two-seeded fruit developing from a superior, *bi-* or *tricarpellary* ovary, with flattened wing-like outgrowths, e.g. *Hiptage* (B. MADHABI-LATA; H. MADHU-LATA; P. MADULATA—fig. 314), *Hopea* (see fig. 328), wood-oil tree (*Dipterocarpus*; B. GARJAN—fig. 313), maple (*Acer*; see fig. 329), etc. In samara the wings always develop from the pericarp, and the fruit breaks into its component parts, each enclosing a seed. *Shorea* (B. SAL) fruit is also a winged one; but here the wings are the dry, persistent sepals. Winged fruit of this nature is known as **samaroid** (see fig. 332).

III. Splitting or Schizocarpic Fruits

1. **Lomentum.** When the legume is constricted or partitioned between the seeds into a number of one-seeded parts, it is called a **lomentum**, as in gum tree (*Acacia*), sensitive plant, ground nut, Indian laburnum (B. SHONDAL; H. & P. AMALTAS), nicker bean (*Entada*; B. GILA), etc.

2. **Cremocarp** (see fig. 209). This is a dry, indehiscent, two-chambered fruit developing from an inferior, bicarpellary ovary. When ripe, the fruit splits apart into two, indehiscent, one-seeded pieces, called *mericarps*. The mericarps remain attached to the prolonged end (carpophore) of the axis. Cremocarp is the characteristic fruit of *Umbelliferae*, e.g. coriander, cumin, fennel or anise, carrot, etc.

Other schizocarpic fruits are: **regma** of castor, **carcerule** of hollyhock, *Abutilon indicum* (B. PETARI; H. KANGHI), basil (*Ocimum*), and **double samara** of maple (*Acer*; see fig. 329).

IV. Fleshy Fruits

Fleshy fruits may be one- or many-chambered, one- or many-seeded, superior or inferior, with axile or parietal placen-

tation. Normally they are *indehiscent, and this being so, seeds* are set free only after the decay of the pulp. In such fruits seeds are distributed mainly through the agency of animals (see 168-70).

1. **Drupe** (fig. 315). This is a fleshy, one- or more-chambered and one- or more-seeded fruit developing from a *monocarpellary* or *syncarpous* pistil, with the pericarp differentiated into the epicarp which forms the skin of the fruit, the mesocarp which is often fleshy, and the *endocarp which is hard and stony*, and hence this fruit is also known as **stone-fruit**, e.g. mango, peach, plum, coconut-palm, palmyra-palm, country almond, etc.

2. **Bacca or Berry** (fig. 316). This is a superior (sometimes inferior), indehiscent, usually many-seeded, fleshy or pulpy fruit developing from a *single carpel* or more commonly from a *syncarpous* pistil, with axile or parietal placentation, e.g. tomato, gooseberry, grapes, brinjal, plantain, guava, papaw, etc. In berry the seeds at first remain attached to the placentae, but afterwards they separate from the placentae and lie free in the plup. It is not infrequent to find one-seeded berry, e.g. date-palm, *Artabotrys* (B. & H. KANTALI-

Fig. 315

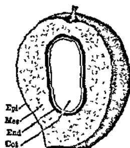


Fig. 316A



Fig. 316B





Fig. 317

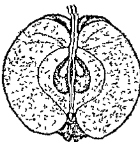


Fig. 318

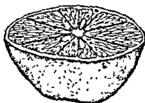


Fig. 319

Fruits (contd.). Fig. 315. Drupe of mango; *epi*, epicarp; *mes*, mesocarp; *end*, endocarp; *cot*, cotyledon. Fig. 316. Berry of tomato; *A*, in longitudinal section; *B*, in transverse section. Fig. 317. Pepo of cucumber in transverse section. Fig. 318. Pome of apple (see also fig. 303). Fig. 319. Hesperidium of orange.

CHAMPA), etc. Epicarp, mesocarp and endocarp may be also distinguished in berry, but it differs from drupe in having *no stony endocarp.*

3. **Pepo** (fig. 317). This is also a fleshy or pulpy, many-seeded fruit like the berry but it develops from an inferior, one-celled or spuriously three-celled, *syncarpous* pistil with parietal placentation. This is the characteristic fruit of gourd family or *Cucurbitaceae*, e.g. gourd, cucumber, melon, water melon, squash, etc. In pepo the seeds, lying embedded in the pulp, remain attached to the placentae.

4. **Pome** (fig. 318). This is an inferior, two- or more-celled, fleshy, *syncarpous* fruit surrounded by the thalamus. The fleshy edible part is composed of the thalamus, while the actual fruit lies within. Examples are found in apple and pear.

5. **Hesperidium** (fig. 319). This is a superior, many-celled, fleshy fruit developing from a *syncarpous* pistil with axile placentation. Here the endocarp projects inwards forming distinct chambers, and the epicarp and the mesocarp, fused together, form the separable skin or rind of the fruit, e.g. orange, shaddock, lemon, etc.

B. Aggregate Fruits

An aggregate fruit develops from a single flower with an *apocarpous* pistil. Carpels being free, each of them develops into a simple fruitlet. An aggregate fruit, therefore, consists of a collection of simple fruitlets—as many as the number of free carpels--borne by a single flower. An aggregate of simple fruitlets borne by a single flower is known as an 'etaerio'. Each fruitlet of an etaerio may be a follicle, an achene, a drupe or a berry. *The common forms are:*

1. **An Etaerio of Follicles.** Common examples are seen in madar, blood flower (*Asclepias*), periwinkle, etc., each etaerio here consisting of a pair of follicles; in larkspur and aconite an aggregate of three folicles is produced on the top of the thalamus; while in *Michelia* numerous follicles (see fig. 749 G-H) are produced on an elongated thalamus.

2. **An Etaerio of Achenes.** Examples are seen in virgin's bower (*Clematis*) and traveller's joy (*Naravelia*; B. CHHAGAL-BATI), where achenes (see fig. 312), provided with feathery, persistent styles, occur in a group; in rose (see fig. 207) achenes remain enclosed in a hollow, receptacular thalamus; in strawberry fruitlets are distributed on the fleshy thalamus; and in lotus (see fig. 208) these occur on a flat, top-shaped, spongy thalamus.

3. **An Etaerio of Drupes.** Example is seen in raspberry (*Rubus*). In it a number of small drupes or drupels, developing from separate carpels of a flower, are aggregated together on a fleshy thalamus.

4. **An Etaerio of Berries.** Berries of custard-apple and bullock's heart, developing from an apocarpous pistil and lying embedded in the fleshy thalamus, grow into a single fruit; while in *Artabotrys* (B. KANTALI-CHAMPA—see fig. 750G), *Unona* (B. LAVENDER-CHAMPA), mast tree (*Polyalthia*; B. DEBDARU; H. DEVADARU or ASHOK) a group of distinct and separate berries is produced.

C. Multiple or Composite Fruits

A multiple or composite fruit is that which develops from a number of flowers juxtaposed together, or in other words, from an inflorescence. Such a fruit is otherwise known as an *infructescence*.

1. **Sorosis** (see fig. 514). This is a multiple fruit developing from a spike or spadix. The flowers fuse together by their succulent sepals and at the same time the axis bearing them grows and becomes fleshy or woody, and as a result the whole inflorescence forms a compact mass, e.g. pine-apple, screwpine and jack-fruit. Mulberry is also a sorosis, but here the fleshy part is made of loosely attached sepals.

2. **Syconus** (see fig. 294). The syconus develops from a hollow, pear-shaped, fleshy receptacle which encloses a number of minute, male and female flowers. The receptacle grows, becomes fleshy and forms the so-called fruit. It really encloses a number of true fruits or achenes which develop from the female flowers lying within the receptacle, e.g. fig, banyan, peepul, etc.

Classification of Fruits

- Simple
  - Dehiscent
    - Legume, e.g. pea
    - Follicle, e.g. madar
    - Siliqua, e.g. mustard
    - Silicula, e.g. *Capsella*
    - Capsule, e.g. cotton
  - Indehiscent
    - Caryopsis, e.g. wheat
    - Achene, e.g. *Clematis*
    - Cypsela, e.g. sunflower
    - Nut, e.g. chestnut
    - Samara, e.g. *Hiptage*
  - Splitting
    - Lomentum, e.g. *Entada*
    - Cremocarp, e.g. carrot
    - Regma, e.g. castor
    - Carcerule, e.g. hollyhock
  - Fleshy
    - Drupe, e.g. mango
    - Berry, e.g. tomato
    - Pepo, e.g. gourd
    - Pome, e.g. apple
    - Hesperidium, e.g. orange
- Aggregate
- Multiple
  - Sorosis, e.g. jack-fruit
  - Syconus, e.g. fig

Some Common Fruits and their Edible Parts

Apple (pome)—fleshy thalamus. **Banana** (berry)—mesocarp and endocarp. **Cashew-nut** (nut)—*peduncle and cotyledons*. **Coconut-palm** (fibrous drupe)—endosperm. **Cucumber** (pepo)—mesocarp, endocarp and placentae. **Custard-apple** (etaerio of berries)—fleshy pericarp of individual berries. **Date-palm** (1-seeded berry)—*pericarp*. *Dillenia* (special)—accrescent calyx. **Fig** (syconus)—fleshy *receptacle*. **Jack** (*sorosis*)—bracts, perianth and seeds. **Grape** (berry)—pericarp and placentae. **Guava** (berry)—thalamus and pericarp. **Indian plum** (drupe)—mesocarp including epicarp. **Litchi** (1-seeded nut)—fleshy aril. **Maize, oat, rice** and **wheat** (caryopsis)—starchy endo-

[illegible])—mesocarp. **Orange**
(fibrous drupe)—meso-
[illegible] ledons. **Pear** (pome)—
[illegible] of receptacle, bracts
[illegible] of the seed. **Pummelo**
[illegible] **Strawberry** (etaerio of
achenes or nuts)—succulent thalamus. **Tomato** (berry)—pericarp and placentae. **Wood-apple** (berry)—mesocarp, endocarp and placentae.

CHAPTER XIII

DISPERSAL OF SEEDS AND FRUITS

If seeds and fruits fall and grow directly underneath the mother plant they tend to exhaust the essential constituents of the soil. Also scarcity of space and light is acutely felt by them under such a condition. A struggle for existence thus ensues for want of food and light, the consequence of which may be fatal to plants. To guard against this and other contingencies plants have developed many devices of a varied nature which will ensure wide distribution of their seeds. Moreover, if seeds and fruits be widely distributed it is most likely that some of them at least would meet with favourable conditions of germination and growth. Thus the risk of a species of plants becoming extinct is practically averted.

I. Seeds and Fruits dispersed by Wind

Seeds and fruits have various adaptations which help them to be carried away by the wind to a shorter or longer distance from the parent plant.



Fig. 320



Fig. 321



Fig. 322



Fig. 323

Winged Seeds. Fig. 320. *Oroxylon*. Fig. 321. *Cinchona*. Fig. 322. *Stereospermum*. Fig. 323. *Lagerstroemia*.

1. **Wings.** Seeds and fruits of many p'ants develop one or more appendages in the form of thin flat membranous wings, and the former also are light and dry ; these devices help them to float in the air and facilitate their dispersion by wind. Thus we find that seeds of *Oroxylon* (B. SONA ; H. ARLU—fig. 320), *Cinchona* (fig. 321), *Stereospermum* (B. PARULI ; H. PARRAL—fig. 322), *Lagerstroemia* (B. & H. JARUL—fig. 323), drumstick (*Moringa*; B. SAJINA ; H. SAINJNA—fig. 324) and *Tecoma* are provided with wings, and when the fruit bursts the seeds are drifted by air current often a long way off. Similarly many fruits are also provided with one or more wings for the same purpose. Some of the common examples of this nature are yam (*Dioscorea* ; fig. 325), ash (*Fraxinus* ; fig. 326), *Terminalia myriocarpa* (B. HOLOK—fig. 327), *Hopea* (fig. 328), maple (*Acer*—fig. 329), wood-oil tree (*Dipterocarpus* ; B. GARJAN—fig. 330), *Hiptage* (B. MADHABI-LATA ; H. MADHU-LATA—fig. 331) and *Shorea* (B. SAL—fig. 332).



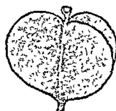
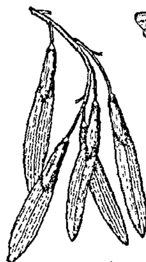


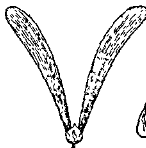
FIG 324 FIG. 325

FIG. 324. Winged seed of drumstick (*Moringa*). FIG. 325. Winged fruit of yam (*Dioscorea*)

FIG. 327







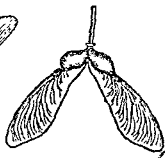
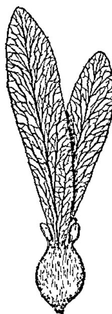


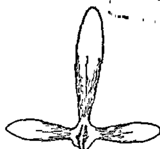
FIG. 326 FIG. 328 FIG. 329

Winged Fruits. FIG 326 Ash (*Fraxinus*). FIG 327. *Terminalia myriocarpa*. FIG. 328. *Hopea*. FIG 329. Maple (*Acer*).

2. **Parachute Mechanism.** In many plants of the sunflower family or *Compositae* the calyx is modified into hair-like

structures, known as **pappus** (fig. 335). This pappus is persistent in the fruit, and opens out in an umbrella-like fashion. As





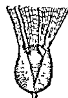


FIG. 330 FIG. 331 FIG. 332
Winged Fruits (*contd.*). Fig. 330. *Dipterocarpus* Fig. 331. *Hiptage.* Fig. 332. *Shorea.*

the fruit gets detached from the parent plant the pappus acts like a parachute and helps it to float in the air. The fruit is often seen to be carried by air current to a great distance.



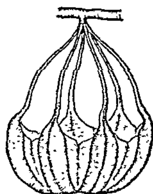


FIG. 333 FIG. 334
Fig. 333. Pelican flower (*Aristolochia*) with duck-shaped flowers. Fig. 334. A fruit of the same like a hanging basket.

3. **Censer Mechanism.** Seeds of certain plants can only be scattered by the wind after the dehiscence of the fruit; in such cases the seeds are often not discharged from the fruit unless the latter is shaken by the wind. Thus in poppy, prickly poppy (*Argemone*), bath sponge, pelican flower (*Aristolochia gigas*; B. HANSA-LATA—fig. 334), etc., the fruit dehisces, and then, when it is disturbed by the wind, the seeds are thrown out.

4. **Hairs.** Seeds of madar (*Calotropis*; fig. 336), blood flower (*Asclepias*), *Holarrhena* (B. KURCHI; H. KARCHI; P. KAWAR), *Beaumontia*—an extensive garden climber with white

FIG. 335 FIG. 336



FIG. 337 FIG. 338

Hairy Fruit and Seeds. Fig. 335. Pappus of a *Compositae* fruit. Fig. 336. Madar (*Calotropis*). Fig. 337. Devil tree (*Alstonia*). Fig. 338. Cotton.

flowers, devil tree (*Alstonia*; B. CHHATIM; H. CHATIUM—fig. 337) and cotton (fig. 338) are provided with hairs either in 1 or 2 tufts or all over their body. These hairs aid in the distribution of seeds by the wind.

5. **Persistent Styles.** In virgin's bower (*Clematis*; H. BELKUN—fig. 339) and traveller's joy (*Naravelia*; B. CHHAGAL-BATI—fig. 340) the styles are persistent and very feathery. The fruits are thus easily carried away by the wind.

6. **Light Seeds and Fruits.** Some seeds and fruits are so light and minute in size that they may easily be carried away by the gentlest breeze. Orchids bear the smallest seeds in the vegetable kingdom. In them millions of dust-like seeds are produced in a capsule, and these are so very minute in size and light in weight as to be easily blown about by the wind like particles of dust. Seeds (fruits) of some grasses are also very small and light. Seeds of *Cinchona* (the quinine-yielding plant) are also very small and extremely light, and provided with a membranous wing (see fig. 321). There are about 70,000 seeds to an ounce.

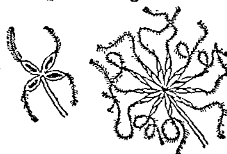


FIG. 339 FIG. 340
Persistent styles Fig 339 Fruits of *Clematis*, Fig. 340. Fruits of *Naravelia*.

II. Seeds and Fruits dispersed by Water

Seeds and fruits to be dispersed by water usually develop floating devices in the form of spongy or fibrous outer coats. The fibrous fruit of coco-nut is capable of floating long distances in the sea without suffering any injury. Hence coco-nut forms a characteristic vegetation of sea-coasts and marine islands. The same is the case with double coconut (*Lodoicea*; fig. 341), a native of Seychelles. The plant bears the largest seeds, and the fruit takes about ten years to ripen. The fruits were seen floating in the Indian Ocean long before the tree was discovered. In lotus (see fig. 208) the spongy thalamus, bearing the fruits on its hemispheric top, floats bodily about in water, being drifted by water-current or by wind. After some time the thalamus rots and the fruits are set free; these sink to the bottom and germinate in time. Sometimes seeds are small and light, and can float on water, e.g. seeds of water lily; these are also provided with an aril which encloses air. When the fruit bursts, the seeds float about on the water. Seeds and fruits of river-side plants are regularly carried downstream by currents.



FIG. 341. Double coco-nut seed (*Lodoicea*).

III. Seeds dispersed by Explosive Fruits

Many fruits burst with a sudden jerk, with the result that seeds are scattered a few yards away from the parent plant. Common examples of explosive fruits are afforded by balsam, wood-sorrel, night jasmine, castor, etc. Ripe fruits of balsam, when touched, burst suddenly. The valves roll up inwards, and the seeds are ejected with great force and scattered in all directions. Many plants of *Acanthaceae* bear explosive fruits which under wet or dry conditions dehisce suddenly from the apex to the base and throw out the seeds with some force. In many such cases the seeds are further provided with jaculators (curved hooks) which straighten out and help in their eject-



FIG. 342. *Ruellia*; note the explosive fruit.

ment. Thus the dry fruits of *Ruellia* (fig. 342) coming in contact with water, usually after a shower of rain, burst suddenly with a noise into two valves, and the seeds are scattered on all sides. Similarly the mature fruits of *Andrographis* (B. KALMEGH; H. MAHATITA), *Barleria* (B. JHANTI; H. VAJRADANTI), *Acanthus* (B. HARGOZA; H. HARKUCHKANTA), etc., burst suddenly when the air is dry, and the seeds are ejected. The cracking sound of the bursting fruits of *Phlox* and *Barleria* is distinctly audible on a bright sunny day.

A very interesting example of bursting fruits is found in camel's foot climber (*Bauhinia vahlii*; B. LATA-KANCHAN; H. CHAMBULI; P. TAUR). Its long pods, sometimes more than a

foot in length explode violently with a loud noise, scattering the seeds in all directions (fig. 343).

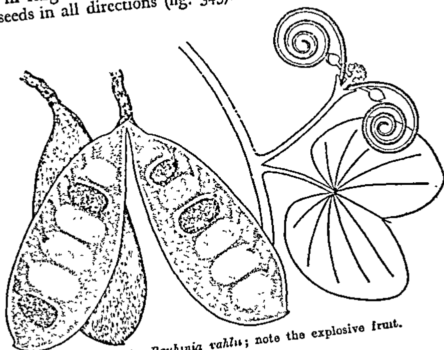


FIG. 343 *Bauhinia vahlii*; note the explosive fruit.

IV. Seeds and Fruits dispersed by Animals

Many seeds and fruits are provided with hooks, burs, barbs, spines, stiff hairs and sticky glands on their surface, by

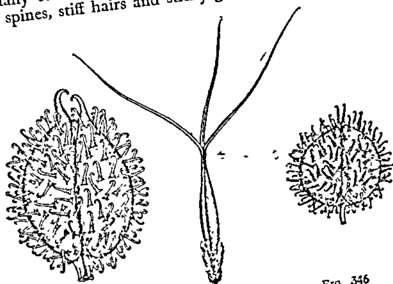
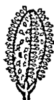


FIG. 344 FIG. 345 FIG. 346

Fig. 344. Fruit of cockle-bur (*Xanthium*) with curved hooks. Fig. 345. Seed (fruit) of spear grass (*Aristida*) with stiff hairs at the base. Fig. 346. Fruit of *Urena* with curved hooks.

means of which they adhere to the body of woolly animals as well as to the clothing of mankind, and are carried far away from the mother plant. Fruits of cockle-bur (*Xanthium* ; B. & H. OKRA ; P. GOKHRU KALAN—fig. 344), *Urena* (B. BAN-OKRA ; H. & P. BACHATA—fig. 346) are provided with numerous curved hooks and those of spear grass (*Aristida* ; fig. 345), love thorn (*Chrysopogon* ; B. CHOR-KANTA) with backward-pointing stiff hairs to achieve the same end. *Pupalia* (B. DUYA-KUYA—fig. 348) affords a very good example of this method of distribution. Here the flowers are small and grow in fascicles. Perianth segments of outer (imperfect) flowers bear hooked bristles which spread outwards. These hooked bristles are very serviceable in the distribution of fruits by animals. The seed of tiger's nail (*Martynia* ; B. BAGH-NAKH ; H. SHERNUI ; P. HATHAJORI—fig. 349) is provided with two very sharp-pointed, stiff and bent hooks, by which it easily sticks to the body of the woolly animal and is effectively dispersed Fruits of chaff-



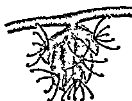




FIG. 347 FIG. 348 FIG. 349

Fig. 347. Fruit of *Boerhaavia* with sticky glands (see also fig. 415). Fig. 348. Flowers of *Pupalia* with hooked bristles. Fig. 349. Fruit of tiger's nail (*Martynia*) with a pair of sharp, curved hooks.

flower (*Achyranthes* ; B. APANG ; H. LATJIRA ; P. KUTRI) with scarious bracts and perianth leaves, and those of hogweed (*Boerhaavia* ; B. PUNARNAVA ; H. THIKRI or SANT—fig. 347) and *Plumbago* (B. CHITA ; H. & P. CHITRAK) with sticky glands are similarly dispersed by animals. In *Tribulus* (B. GOKHRU-KANTA ; H. GOKHRU ; P. BHAKHRA) there are sharp rigid spines on the fruit, by which it sticks into the foot of the hoofed animal and is easily dispersed.

Seeds of many fleshy fruits, more particularly with conspicuous colour, are widely distributed by birds. They feed upon the pulpy fruits such as guava, grape, fig, etc., and pass out the undigested seeds with the faeces ; the seeds then germinate.

Fig, banyan and peepul are commonly seen growing on the trunk of the date-palm tree. In all these cases seeds have been left there by birds and squirrels. In mistletoe (*Viscum*; see fig. 69), a semi-parasite on mango and other trees, seeds are very sticky and easily stick to the beak of the bird which feeds upon the fruits. The bird brushes its beak against the branch of a tree so that the seeds stick to it again and germinate under favourable conditions. Many birds, as they wade in water or bathe in it, carry small seeds and fruits of aquatic plants on their body from one pond to another. They also carry fruits from one place to another. Jackals feed upon dates, plums, etc., and the seeds germinate after passing through their alimentary canal. Bats and squirrels are also useful agents for the dispersal of seeds and fruits. Plants with edible fruits or ornamental flowers, or with medicinal properties or those of any economic importance, are widely distributed through the agency of mankind.

PART II
HISTOLOGY

CHAPTER I

THE CELL

An Early History. The study of histology dates from the year 1665, when plant cells were discovered for the first time. It was Robert Hooke, an Englishman, who first studied the internal structure of a thin slice of bottle cork with the help of a microscope improved by himself He discovered for the first time a honeycomb-like structure in it, and to each individual cavity of such a structure he applied the term **cell.** It was then only the cell-wall that was noticed, this being the prominent part of the cell.

Other prominent workers of that time, who studied plant tissues under the microscope, were Leeuwenhoek, Grew and Malpighi. Leeuwenhoek of Delft in Holland was the first to invent the microscope. He was a dry-goods dealer but at the age of 21 in the year 1653 he developed a mania for grinding lenses. He pursued this work with all zeal and assiduity and within 20 years (1653-1673) accomplished marvellous fineness, accuracy and perfection in his lenses. He gave a demonstration of his microscope before the Royal Society in 1667. He was the first to discover bacteria, protozoa and other minute forms of life—'the wretched beasties', as he called them, under his own microscope. Grew, an English physician and botanist, published his first paper on plant tissues in 1671. Malpighi, an Italian physician, studied the various tissues of vascular plants, and published his first paper in 1675.

In 1838-39 Schleiden, a German botanist, and Schwann, a German zoologist, proved definitely that both plants and animals are cellular in character, and founded the **cell-theory.** Each cell of the living tissue was seen to be filled with a semi-fluid, granular substance. To this [illegible] substance of the plant cell the name **protoplasm** was proposed by [illegible] in 1846. Cohn in 1850 established the fact that plant protoplasm and animal protoplasm are identical.

de Bary [illegible] animal cells [illegible] protoplasm theory [illegible] that the cells [illegible] each mass containing a nucleus. The cell-wall of plant [illegible] nent under the microscope, is of secondary importance, [illegible] by the protoplasm for its own advantage.

The nucleus of the cell was first discovered by [illegible] The first satisfactory account of the structure of the [illegible] of division were however given by Strasburger in the [illegible] was recognized by Strasburger, Weismann and others [illegible] concerned in the problem of inheritance of characters.

Cell-structure. Cells are the fundamental [illegible] functional units that the plant body [illegible] composed of. A plant cell may be [illegible] pendent, tiny or microscopic mass of protoplasm [illegible] in it a denser spherical or oval body [illegible]

bounded by a distinct wall, called the **cell-wall.** Protoplasm and nucleus *are living, while the cell-wall is non-living,* the latter having been formed by the protoplasm primarily for its own protection. The living parts of a cell (protoplasm, nucleus

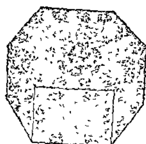


Fig. 350

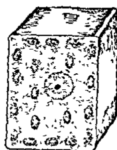


Fig. 351

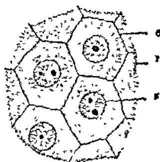


Fig. 352

Plant Cells Fig. 350. A polygonal cell (three-dimensional diagram). Fig. 351. A cubical cell in section (three-dimensional diagram). Fig. 352. A group of cells in section; *C*, cell-wall; *P*, protoplasm; *N*, nucleus.

and other living bodies) together constitute the **protoplast** of the cell—a collective and convenient term introduced by Hanstein in 1880. A plant cell thus consists of a protoplast (representing the living parts) and a cell-wall (forming a non-living framework round the protoplast to maintain its shape and firmness and to afford necessary protection).

Cells vary widely in shapes and sizes. In shapes they may commonly be spherical, oval, polygonal, rectangular or considerably elongated.

or of like nature.

to the naked eye.

or polygonal cells varies between $\frac{1}{10}$ and $\frac{1}{100}$ *of a millimetre.* Sometimes, as in fleshy fruits and pith, they may be as big as 1 mm. or even bigger, or as small as $\frac{1}{200}$ mm. or even smaller. Among the known cells bacteria are the smallest, usually ranging between $\frac{1}{100}$ and $\frac{1}{1000}$ mm. or even smaller. Still smaller in size are the viruses which defy microscopic observation. Fibrous cells are considerably elongated; they chiefly vary in length from 1 to 3 mm., but in woody stems they may often be as big as 6 mm. or even 8 mm. In some fibre-yielding plants such as flax, hemp and rhea the fibrous cells may grow to a length of 20 to 550 mm. Still larger cells are the latex cells.

THE PROTOPLAST

The protoplast is the living unit—actually the physiological unit—of a cell, while the **protoplasm** is the essential living material that comprises the different parts of it (the protoplast).

Protoplasm is the only substance that is endowed with life and, therefore, plants and animals containing this substance in their body are regarded as living. As the protoplasm dies the cell ceases to perform any function for the plant or the animal, and the latter (plant or animal) as a whole then dies. Protoplasm is thus fitly described as the *physical basis of life.* As the protoplast as a whole has to carry on manifold functions of a cell, such as manufacture of food, nutrition, growth, respiration, reproduction, etc., it is differentiated into distinct living (protoplasmic) bodies: (1) cytoplasm, (2) nucleus, and in special cells (3) plastids. These are only masses of protoplasm differentiated into distinct bodies (fig. 353C) to carry on specialized functions. It must, however, be noted that these *living bodies are never formed de novo in the cells but they* always develop from pre-existing ones and that one kind of living body cannot give rise to another kind.

1. **Cytoplasm.** The protoplasmic mass of a cell leaving out the nucleus and the plastids is otherwise called cell-protoplasm or **cytoplasm.** When the cell is young the cytoplasm fills in the space between the cell-wall and the nucleus. The surface of the cytoplasm forms into an extremely thin and delicate membrane known as the **plasma membrane** or **ectoplasm.** This plasma membrane is also hyaline but non-granular and somewhat firmer in consistency than the rest of the cytoplasm, and it lies adpressed against the cell-wall. This is a very important layer controlling the entrance and exit of substances into the cell and out of it. The inner granular mass of the cytoplasm is often called **endoplasm.** Under the microscope it is often

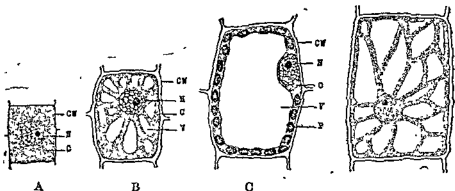


Fig. 353 Fig. 354

Fig. 353. Plant cells, young and old, showing increase in size and development of vacuoles. *CW*, cell-wall; *N*, nucleus; *C*, cytoplasm; *V*, vacuole; and *P*, plastid. Fig. 354. A cell with many small vacuoles.

seen that the cytoplasm encloses numerous minute granules whose nature is obscure; these are known as the *microsomes.*

In the young cell the cytoplasm completely fills the cavity, but as the cell increases in size it develops a number of small cavities or **vacuoles** (*vacuus*, empty) of varying sizes. With the growth of the cell all these may soon fuse together forming a big vacuole which occupies nearly the whole of the central part of the mature cell, and then the cytoplasm forms a thin layer lining the cell-wall, with the nucleus and the plastids lying embedded in this layer (fig. 353C); or the cytoplasm may occur as delicate strands radiating from around the nucleus, and often suspending it in the cavity of the cell; under this condition several small vacuoles appear in the cell between the cytoplasmic strands (fig. 354). The vacuole is filled with a fluid known as the **cell-sap.** In the young condition of the cell the cell-sap permeates the cytoplasm. Dissolved in the cell-sap, or lying in a state of suspension in it, there occur various chemical compounds (see pp. 201-2). The vacuole is thus regarded as the store-house of water, mineral salts, certain food substances, etc. The layer of cytoplasm in contact with the vacuole and surrounding it as a membrane is known as the **vacuole membrane or tonoplasm.**

Physical Nature of Protoplasm. Protoplasm is a transparent, foamy or granular, slimy, semi-fluid substance, somewhat like the white of an egg. It is never homogeneous but contains granules of varying shapes and sizes, and it really looks finely granular under the microscope. Although often semi-fluid it may be fluid or viscous. It occurs completely filling up the cavity of the young cell but in a mature cell it forms a thin layer lining up with the cell-wall (fig. 353C), often forming arms or strands connecting the nucleus (fig. 354). In its *active* state the protoplasm remains saturated with water containing 75-90% of it. With decreasing water content its vital activity diminishes and gradually comes to a standstill, as in dry seeds. Protoplasm coagulates on heating, and when killed it loses its transparency.

Structure. Protoplasm, as it works in the cell, undergoes dynamic physical changes and, therefore, its ultimate structure cannot be known with any amount of certainty. So from time to time its structure has been variously expressed as (a) **fibrillar** consisting of interlacing fine fibres or fibrils, (b) **foamy** consisting of a froth of minute bubbles, and (c) **granular** consisting of fine grains or granules more or less uniformly dispersed throughout the protoplasm.

Protoplasm responds to the action of external stimuli such as needle- or pin-prick, electric shock, application of particular chemicals, sudden variation of temperature or of light, etc. On stimulation the protoplasm contracts but expands again when the stimulating agent is removed. This 'contractility' involv-

ing both contraction and expansion, first demonstrated by Kuhne in 1864 in the staminal hair of spiderwort, is an inherent power of protoplasm.

Protoplasm is semi-permeable in nature, i.e. it allows only certain substances and not all to enter its body. This property is however lost when the protoplasm is killed.

Under normal conditions the protoplasm of a living cell is in a state of constant motion. Under the microscope it generally shows two different kinds of movements, commonly called streaming movements (see pp. 176-7).

Chemical Nature of Protoplasm. Chemically protoplasm is a highly complex mixture of a variety of chemical substances of which proteins are the chief. The exact chemical composition of the living protoplasm cannot be determined because any attempt to analyse it kills it outright with some unknown changes in it. Besides, it undergoes continual changes and its composition is not, therefore, constant. Further, protoplasm always encloses many foreign substances in its body in varying quantities and, therefore, it is not possible to get the protoplasm in a pure state. Analysis of the dead protoplasm reveals a long list of elements present in it. Of these oxygen (O), carbon (C), hydrogen (H) and nitrogen (N) are most abundant. Other elements present in smaller quantities are: chlorine (Cl), sulphur (S), phosphorus (P), silicon (Si), calcium (Ca), magnesium (Mg), potassium (K), iron (Fe) and sodium (Na). In traces are also present the following: zinc (Zn), manganese (Mn), aluminium (Al), copper (Cu), boron (B) and molybdenum (Mo) and often a few others. Active protoplasm contains a high percentage of water—usually varying from 75-90%, and remains saturated with it. Leaving out this water the solid matter of the protoplasm contains the following: proteins—40-60%; fatty substances (true fats and lipids, particularly lecithin)—12-14%; carbohydrates—12-14%; and inorganic salts—5-7%.

Colloidal State of Protoplasm. The constituents of protoplasm, mainly proteins, form a **colloidal system.** In a colloidal state a matter is divided into very fine particles—aggregations of molecules, and not individual molecules as in a solution, which are dispersed through a continuous medium, mostly a liquid or a semi-solid. In the case of protoplasm the dispersion medium is water with dissolved salts and other substances in it, and the colloidal particles of proteins are dispersed through this medium. A colloid exists as a mixture and not as a compound but the colloidal particles are mostly not filterable through a fine parchment membrane. In many colloids the particles are stable, while in others these are unstable settling down under slight chemical or physical change. A colloidal mixture may be fluid or viscous. A fluid colloid is called a sol, and a viscous colloid a gel. Protoplasm mostly exists in the state of a sol but may change to a gel under certain conditions, the changes being reversible. But

when it dies it cannot change from one state to the other. The colloidal system of protoplasm is believed to be responsible for its various life-processes.

Tests. (*a*) **Iodine** solution stains protoplasm **brownish yellow.** (*b*) **Dilute caustic potash** dissolves it (*c*) **Millon's reagent** (nitrate of mercury) stains it brick-red, the reaction is hastened by heating.

Movements of Protoplasm. Protoplasm shows movements of different kinds. Naked masses of protoplasm, not enclosed by the cell-wall, show two kinds of movement—**ciliary** and **ameoboid.** The protoplasm, enclosed by the cell-wall, shows a streaming movement within it, which is spoken of as *cyclosis.* Cyclosis is of two kinds—**rotation** and **circulation.**

(1) **Ciliary movement** (fig. 355) is the *swimming* movement of free, minute, protoplasmic bodies such as the zoospores of many algae and fungi, bacteria, antherozoids of mosses and ferns, etc., provided with one or more special organs of motion in the form of whip-like structures, called cilia or flagella. By the vibration of these cilia such ciliary bodies move or swim freely and rapidly in water.

(2) **Amoeboid movement** (fig. 356) is the *creeping* movement of naked masses of protoplasm such as slime fungi, certain

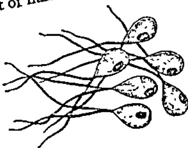


FIG. 355

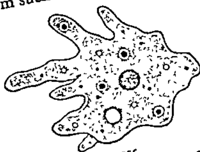


FIG. 356

Movements of Protoplasm. Fig. 355. Ciliary movement. Fig. 356. Amoeboid movement.

zoospores, etc. They move or creep by the protrusion of one or more parts of their body in the form of false feet or pseudopodia (*pseudos*, false; *podos*, foot) and withdrawing the same at the next moment, very much like the animalcule *Amoeba.* Cell-wall being absent, the protoplasmic mass has got no definite shape, and is capable of engulfing solid particles of food.

(3) **Rotation** (fig. 357). When the protoplasm moves or streams alongside the cell-wall, clockwise or anti-clockwise, round a large central vacuole, the movement is expressed as a rotation. The direction of movement is constant so far as a particular cell is concerned. As the protoplasm rotates, it

carries in its current the nucleus and the plastids. Rotation is distinctly seen in *Vallisneria, Hydrilla, Chara* and *Nitella,* and also in many other aquatic plants.

(4) **Circulation** (fig. 358). When the protoplasm moves or *streams* in different directions in a cell round a number of small vacuoles, the movement is called circulation. In this process a mass of protoplasm around the nucleus radiates in different directions in the form of delicate strands; each strand then moves round a vacuole and finally comes back to the nucleus. Circulation is very distinctly seen in the purplish

FIG. 357

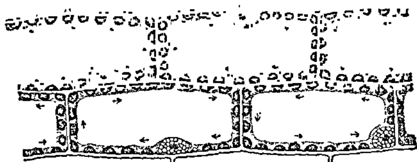


FIG. 358



Movements of Protoplasm (*contd.*). Fig. 357. Rotation in the leaf of *Vallisneria.* Fig. 358. Circulation in the staminal hair of *Commelina obliqua.*

staminal hairs of *Commelina obliqua* (B. JATA-KANSHIRA; H. KANJURA). It is also seen in the staminal hairs of spiderwort (*Tradescantia*), in the young shoot-hairs of gourd, elephant ear plant (*Begonia*) and in many other land plants.

2. **Nucleus.** Embedded in the cytoplasm there is a specialized protoplasmic body, usually spherical or oval in shape and much denser than the cytoplasm itself; this is the **nucleus.** Its shape depends to some extent on the nature of the cell in which it occurs. In the young cell it occupies a median position and is almost always spherical or oval; but in the long cell it may become correspondingly elongated. In the mature cell with the formation of the vacuole it lies in the lining layer of the cytoplasm and may become flattened against the cell-wall.

Nuclei are universally present in all living plant cells. In the higher plants only a single nucleus is present in each cell; in the latex tissue (see figs. 412-3), and in many algae and fungi numerous nuclei are often seen in a single cell. In some lower organisms, however, true nuclei are absent, but there is corresponding nuclear material. Nuclei may vary widely in size from $\frac{1}{2}$ mm. to $\frac{1}{1000}$ mm. Their usual size, however, is between $\frac{1}{40}$ mm. and $\frac{1}{200}$ mm. A nucleus can never be newly formed, but it multiplies in number by division of the pre-existing one.

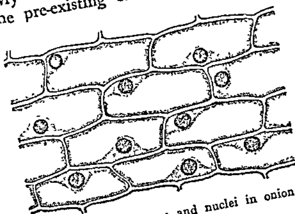


FIG. 359. Cellular structure and nuclei in onion scale.

Structure. Each nucleus (fig. 360) is surrounded by a thin, transparent membrane known as (1) the **nuclear membrane** which separates the nucleus from the surrounding cytoplasm. The shape of the nucleus depends partly on it. Within the membrane, completely filling up the space, there is a dense but clear mass of protoplasm known as (2) the **nuclear sap** or **nucleoplasm** or **karyolymph.** Suspended in the nucleoplasm there are numerous, fine, crooked threads, loosely connected here and there, forming a sort of network, called (3) the **nuclear reticulum** or **chromatin network.** The threads are made of a substance known as **chromatin** or **nuclein** which is strongly stainable. The chromatin is a nucleoprotein which is a phosphorus-containing protein. One or more highly refractive, very minute and usually spherical bodies, much denser than the nucleoplasm, also occur in the nucleus; these are known as (4) the **nucleoli.**

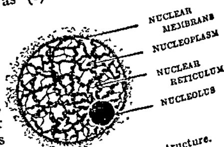


FIG. 360. Nuclear structure.

Nucleoli remain attached to certain chromosomes in their particular regions. They are, therefore, regarded as parts of those chromosomes Nucleoli act as reservoirs of nucleoproteins which become converted into proteins and nucleic acid during mitosis.

Chemical Composition. The chemical composition of the nucleus is more or less similar to that of the cytoplasm. It is composed of proteins and protein-like substances. It contains a material, known as *nuclein.* Chemically this nuclein is a *nucleoprotein which contains phosphorous in addition to* carbon, hydrogen, oxygen, nitrogen and sulphur. Nuclein is present in the reticulum, but not in the nucleoplasm. The *nucleus is slightly alkaline.*

Functions. The nucleus and the protoplasm are together responsible for the life of a cell. When a protoplast is segmented into two parts, the part containing the nucleus has the power to reconstruct a wall round itself and carry on normal functions; whereas the part without the nucleus dies. The nucleus is, however, regarded as the controlling centre of vital activities of the cell, particularly assimilation of food and respiration. The specific functions carried on by the nucleus, of course, assisted by the protoplasm, are as follows:

1. The nucleus takes a direct part in reproduction. For *asexual reproduction a nucleus usually divides twice to give* rise to a group of four cells, called spores; while for sexual reproduction two reproductive nuclei, called gametes, fuse together to give rise to an oospore which grows into an embryo. Thus nuclei are directly concerned in the process of reproduction.

2. The nucleus takes the initiative in cell-division, i.e. it is the nucleus that divides first and this is followed by the division of the cell. The egg-cell divides to give rise to the embryo. The cells of the embryo likewise divide to form the body of the plant. It is evident, therefore, that but for repeated nuclear divisions the body of the plant could not have been built up.

3. The nucleus is regarded as the *bearer* of hereditary characters. It is evident that the characteristics of the parent plants are inherited by the offspring. These are transmitted from the parental bodies to the offspring through the media of two reproductive nuclei, i.e. the egg-cell and the male gamete, during the reproductive stage in the life-history of a plant. These nuclei carry in their body all the characteristics of the parent forms and transmit them to the offspring.

3. **Plastids.** Besides the nucleus, the cytoplasm of a cell encloses many small specialized protoplasmic bodies, usually

discoidal or spherical in shape; these are called **plastids** (see fig. 357). The ground substance of the plastids is called the **stroma;** lying embedded in the stroma there is a large number of granules. The stroma is colourless, whereas the granules contain the pigment or colouring matter. Plastids are living. They are never formed afresh, but multiply in number by division of the pre-existing ones. At an early stage of the cell, as in the young bud, they appear as very small granules or rods (proplastids). But as the cells grow, the plastids also grow, multiply and assume their characteristic forms. They occur in cells which have to carry on specialized functions, and are always absent from blue-green algae, fungi and bacteria. Plastids are of three types, viz. **leucoplasts, chloroplasts** and **chromoplasts.** One form of plastids can change into the other; as for example, leucoplasts change into chloroplasts when the former are exposed to light for a prolonged period; similarly, chloroplasts change into leucoplasts in the continued absence of light; similar changes may take place in chromoplasts. In the young tomato fruit the leucoplasts gradually change into chloroplasts which finally turn into chromoplasts as the fruit ripens.

(1) **Leucoplasts** (*leucos*, white). These are colourless plastids. Leucoplasts occur most commonly in the storage cells of roots and underground stems; they are also found in other parts not exposed to light. They vary in shape, being frequently spherical, discoidal or rod-like. Leucoplasts are of two kinds: small and large. The smaller one may develop into the larger type or into the chloroplast or the chromoplast. The larger type known as **amyloplast** (starch-builder) forms large starch grains from soluble sugars for the purpose of storage in the underground and other storage organs of plants.

(2) **Chloroplasts** (*chloros, green*). These are green plastids, their colour being due to the presence of a green *pigment* (colouring matter), called **chlorophyll**; sometimes the green colour may be masked by other colours. Chloroplasts are only found in parts exposed to light; they occur abundantly in green leaves, and also to some extent in green parts of the shoot. They are mostly spherical or discoidal in shape, but in some bryophyta and algae they may assume peculiar forms. *Functions.* They work *only in the presence of sunlight* and carry on some very important functions with the help of their chlorophyll. They absorb carbon dioxide from the air; manufacture sugar and starch from this carbon dioxide and the water absorbed from the soil; and liberate oxygen (by splitting the water) which escapes to the surrounding air.

Chlorophyll is not one simple substance, but a mixture of four different pigments, viz. chlorophyll *a* (blue-black), chlorophyll *b* (green-black), carotin (orange-red) and xanthophyll (yellow). Chlorophyll *a* and chlorophyll *b* are associated with each other in the chloroplast, but carotin and xanthophyll may also occur without chloroplast in any part of the plant. Chlorophyll as a whole can be easily extracted with alcohol or chloroform and the leaves then become colourless. To hasten this extraction the leaves may be previously boiled for a few minutes. The chlorophyll solution appears deep green in transmitted light, but blood-red in reflected light. This is the physical property of chlorophyll, called *fluorescence*. A mixture of the two pigments—carotin and xanthophyll, which are always associated with chlorophyll, can be easily separated from the chlorophyll solution by shaking it with a small quantity of benzene and allowing the solution to settle for a few minutes; the benzene floats on the top (green solution) carrying chlorophyll, while alcohol settles at the bottom (yellow solution) retaining carotin and xanthophyll. Instead of benzene, ether or olive-oil may be used. Chlorophyll is not soluble in water, even under prolonged boiling. Chlorophyll forms about 8% of the dry weight of the chloroplast, while carotin and xanthophyll about 2%. *Functions*. It is definitely known that chlorophyll absorbs energy from the sunlight. It may also help in the chemical process involved in the manufacture of food by the chloroplasts.

Chemical composition of chlorophyll

Chlorophyll *a*	—$C_{55}H_{72}O_5N_4Mg$
Chlorophyll *b*	—$C_{55}H_{70}O_6N_4Mg$
Carotin	—$C_{40}H_{56}$
Xanthophyll	—$C_{40}H_{56}O_2$

(3) **Chromoplasts** (*chroma*, colour). These are variously coloured plastids—yellow, orange and red. They are mostly present in the petals of flowers and in fruits, and the colouring matters (pigments) associated with them are **xanthophyll** (yellow) and **carotin** (orange-red). Various other colours are formed as a result of combinations of red, yellow and green. The function of pigments occuring in flowers is to attract insects for pollination (see p. 139). Carotin is a hydro-carbon, i.e. it consists of carbon and hydrogen, its formula being $C_{40}H_{56}$, and xanthophyll is an oxidation product of carotin, i.e. it has oxygen in addition, its formula being $C_{40}H_{56}O_2$.

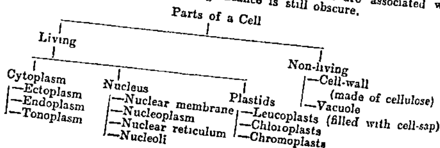
Colours of most violet or purple and blue flowers and also of many red and brown ones are, however, due to pigments—anthocyanins, *dissolved in the cell-sap*. Anthocyanins occur in flowers, in coloured roots, e.g. beet-root, and in colorred stems, e.g. balsam stem. They also occur in the

variegated leaves of garden crotons and amaranth, and in the young red leaves of many plants, e g. mango, country almond, etc., and frequently mask the chlorophyll. They possibly serve as a screen to the chloroplasts, protoplasm, etc, and protect them against strong sunlight. Occurring in flowers they, of course, serve to attract insects for pollination. They are soluble in water and alcohol When a coloured leaf is boiled with water, anthocyanins are extracted and the leaf then appears greenish due to the presence of chlorophyll Anthocyanins are capable of changing their colour. The colour depends upon the reaction of the sap of the cells in which they occur; the colour is red when the sap is acid, and it is blue when the sap is alkaline in reaction. In addition to these there are various other pigments present in the plant body.

Centrosomes. These occur as minute granules near the nucleus of animal cells and in some lower plants such as algae and fungi. They are not found in seed plants. During nuclear division the centrosome divides into two and these pass on to the two poles of the spindle forming the centres of cytoplasmic radiations—the 'asters'.

Chondriosomes or Mitochondria. These are very small bodies present in the cytoplasm of nearly all plant and animal cells. They may occur in the form of rods, granules or filaments and are largely composed of protein and lipoid (a fatty substance) They have certain characteristic staining properties and can be demonstrated only after special treatments. There are diverse views regarding their structure and origin, and according to some investigators they are the starting points of the different types of plastids. They are also said to be connected with respiration and secretion of enzymes.

Golgi Bodies. These occur as more or less conspicuous, net-like, small bodies in the cytoplasm as seen after special method of preparation. They were first noted in animal cells and are more abundant in them than in plant cells. In gland cells of animals golgi bodies are associated with secretions, but in plants their significance is still obscure.



THE CELL-WALL

Formation of the Cell-wall. Life begins as a single naked cell, that is, as a small mass of protoplasm with a prominent nucleus but no cell-wall. Protoplasm being a very soft and delicate substance, its first need is self-protection. For this purpose, before it grows any further in size or undergoes division, it forms a wall round itself. It secretes minute granules on the outer surface of its body. These granules increase in number and ultimately fuse together. When they have fused together the result is a complete wall, i.e. the cell-wall, and the protoplasm becomes invested by it. The cell-wall forms a framework round the protoplast, maintains its form and pro-

tects it from external injury. Besides, cell-walls form the skeleton of the plant body, and are responsible for its strength and rigidity.

Growth of the Cell-wall. The cell-wall, when formed first, is a very thin and delicate layer. As the cell grows we find changes—both chemical and physical—in the cell-wall. Physical changes are: growth of the wall in surface extent and growth of it in thickness. (1) Growth of the cell-wall in surface extent, i.e. its increase in size, takes place in the early stage of the cell and is due to stretching of the cell-wall in one or more directions accompanied by an intercalation, within the original wall, of new solid particles secreted by the protoplasm. This method is known as **growth by intussusception.** (2) Growth of the cell-wall in thickness, on the other hand, is mainly due to deposition of definite thin plates or layers by the protoplasm, one after another, on the inner surface of the original wall. This method is known as **growth by apposition.** When the cell-wall becomes considerably thickened, it shows a *stratified* appearance, that is, the appearance of a number of strata or layers arranged in a series. The original cell-wall between two contiguous cells can still be recognized under the microscope. This original or middle wall is known as the **middle lamella** (fig. 361). It consists of a substance, called calcium pectate. It is further seen that the protoplasm of one cell is connected with that of the neighbouring one by fine protoplasmic threads or strands passing through extremely minute pits (not visible under the microscope) that develop in the cell-wall. Each of these protoplasmic strands is called a **plasmodesma** (pl. plasmodesmata; fig. 361). It must be noted that the cell-wall grows in thickness in stages. The cell-wall originally formed by the protoplasm as a very thin layer continuous with the protoplasm and made of pectose is called the *primary wall*. The primary wall common to two contiguous cells, evidently formed by both of them, is called

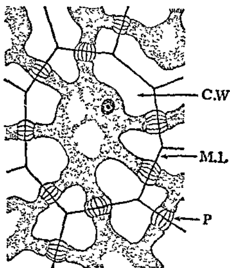


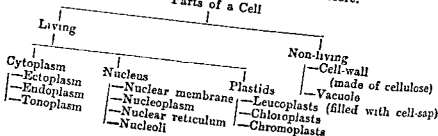
FIG. 361. Cells from the endosperm of date seed. *C.W*, cell-wall (hemicellulose, see p. 193); *M.L.*, middle lamella; *P*, plasmodesma.

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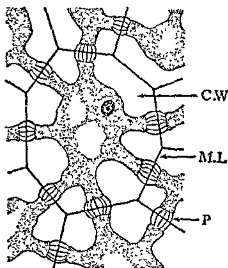


FIG. 361. Cells from the endosperm of date seed. *C.W*, cell-wall (hemicellulose, see p 193); *M.L.*, middle lamella; *P*, plasmodesma.

the middle lamella, as stated above. Fresh layers laid down against the primary wall by the process of apposition form the *secondary wall*. It consists of pectose and cellulose. A *tertiary wall* made of pure cellulose is soon laid down against the secondary wall. The secondary and tertiary walls cannot, however, always be distinguished. Both these walls may finally become lignified.

Thickening of the Cell-wall. The thickening of the cell-wall takes place in those cells which have ultimately to grow up into vessels (see pp. 218-9) and tracheids (see p. 218); after such cells have grown considerably and attained full dimension their walls begin to thicken. The thickening in these cases is due to deposit of a hard substance, called **lignin**, on the inner surface of the cell-wall. This deposit of lignin seldom occurs uniformly all round the cell-wall, but most commonly it is localized in particular portions of it in various patterns; the major portion of the wall remains unthickened. The patterns of thickening may be:

1. **Annular or ring-like** (fig. 362), when the deposit of lignin is in the form of rings which are placed, one a little above the other, in the interior of the original cell-wall, the remaining portion of the wall being unthickened.

2. **Spiral** (fig. 363), when the thickening takes the form of a spiral band.

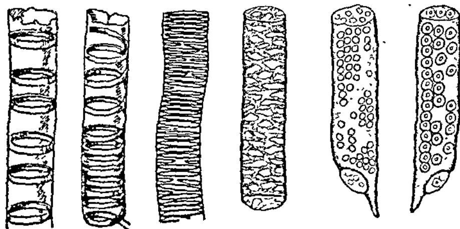


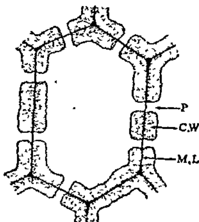
FIG. 362 FIG. 363 FIG. 364 FIG. 365 FIG. 366 FIG. 367
Thickening of the Cell-wall. Fig. 362. Annular. Fig. 363. Spiral. Fig. 364. Scalariform. Fig 365. Reticulate. Fig. 366. Pitted (with simple pits). Fig. 367. Pitted (with bordered pits).

3. **Scalariform or ladder-like** (fig. 364), when the thickening matter or lignin is deposited transversely in the form of

rods or rungs of a ladder, and hence the name scalariform or ladder-like. Unthickened portions of the wall appear as elongated transverse pits, while the thickened spaces between them give a ladder-like appearance to the wall (see also fig. 400).

4. **Reticulate or netted** (fig. 365), when the thickening takes the form of a network, evidently leaving a number of irregular unthickened spaces in the wall.

5. **Pitted** (figs. 366-70), when the whole inner surface of the cell-wall is more or less uniformly thickened, leaving here and there some small unthickened areas or cavities. These unthickened areas are called **pits,** and are of two kinds, viz. (*a*) **simple pits** and (*b*) **bordered pits.** Pits are formed in pairs lying against each other on the opposite sides of the wall. The portion of the original wall separating the two opposing pits is called the *closing membrane.* The closing membrane in the bordered pits shows a slight swelling or thickening in the middle, called *torus* (fig. 370A). When the area of a pit is uniform throughout its whole depth, it forms a simple pit (figs. 368-9); and when this area is unequal, broader towards the wall and narrower towards the cavity of the cell, more or less like a funnel without the stem, it forms a bordered pit (fig. 370B). In the bordered pit the adjoining thickening matter of the wall grows inwards and arches over the pit from all sides forming an overhanging border, and hence the name 'bordered' pit. In surface view the simple pit may be circular, oval, polygonal, elongated or somewhat irregular; while the bordered pit is often circular or oval. Pits are areas through which diffusion of liquids takes place more easily. In bordered pits this diffusion is regulated to a great extent by the torus which, when pushed from one side, blocks the pit. Through simple pits, contained in the living cells, diffusion of protoplasm also takes place. Bordered pits are abundantly found in the tracheids of conifers (e.g. pine) and in the vessels of angiosperms; simple pits are also found in them, but they are more



Simple Pits. FIG 368. A cell in section showing simple pits in its wall; *P*, pit; *C.W*, cell-wall; *M.L*, middle lamella.

frequent in some of the living cells, and occur largely in the

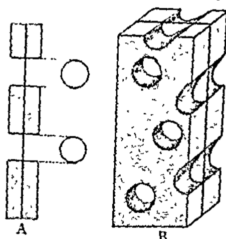


Fig 369

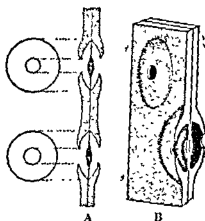


Fig. 370

Simple pits. Fig. 369. *A*, cell-wall with two simple pits—sectional and surface views; *B*, portion of a cell-wall (in perspective) with some simple pits—sectional view (right and top) and surface view (front).
Bordered pits. Fig. 370. *A*, cell-wall with two bordered pits—sectional and surface views; *B*, a portion of the cell-wall (in perspective) with two bordered pits—sectional view (bottom) and surface view (top).

wood parenchyma, medullary rays, phloem parenchyma, com-

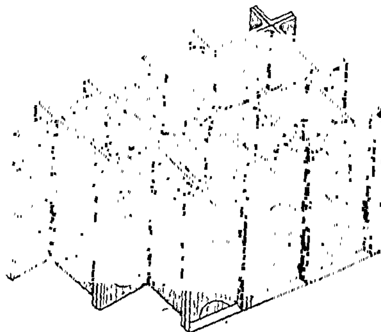


Fig. 371. Tracheids with bordered pits of pine stem (diagrammatic).

panion cells, etc. Fibres are often provided with simple oblique

pits and sometimes also with bordered pits, and stone cells with simple, branched pits.

Chemical Nature of the Cell-wall. The cell-wall consists of a variety of chemical substances, of which cellulose is very conspicuous; but as the cell grows older, cellulose undergoes chemical changes and a variety of new substances is formed. Many mineral matters are also often introduced into the cell-wall.

Cellulose. The wall of the young cell is composed of a substance, called **cellulose**; associated with it are other substances, of which pectic compounds are conspicuous. When first formed the wall is fundamentally composed of pectin which soon becomes converted into insoluble pectate of calcium, as in the middle lamella. Pectin acts as a cementing material holding together the cells of the plant body very much like the bricks of a brick-wall. Later both pectin and cellulose form the wall substance, and later still pure cellulose is secreted by the protoplasm. Cellulose is universally present in the cell-walls of all the soft parts of plants with the exception of fungi. It is a soft, elastic and transparent substance, and is readily permeable to water. Walls made up of cellulose are usually thin, and the cells living containing protoplasm. Chemically, it is a carbohydrate which contains the elements carbon, hydrogen and oxygen, the latter two existing in the same proportion as they do in water. It is represented by the formula $(C_6H_{10}O_5)n$, the value of *n* not being known. Cellulose is a very important substance. It is used as food by herbivorous animals; it cannot, however, be digested by human beings. Articles like paper gun-cotton, celluloid and artificial silk are prepared from it. Cotton and linen are pure cellulose, while hemp is a mixture of cellulose and lignin.

Tests. (*a*) **Iodine solution** followed by a drop of 50 per cent **sulphuric acid** or concentrated **zinc chloride** makes cellulose walls **blue or violet.** (*b*) **Chlor-zinc-iodine** turns cellulose **blue or violet.** (*c*) **Phosphoric acid iodine** stains cellulose **violet.**

Pectic compounds occur in plants in three forms. insoluble pectose, soluble pectin and insoluble pectic acid. One form may change into the other in the plant body. Pectin swells in water into mucilage, as the gelatinous sheath of *Spirogyra*. It is present in many fruits and vegetables, and is responsible for the setting of jellies made from fruits Pectin, present in the cell-walls, acts as a binding or cementing material holding together cells of the plant body. A large proportion of pectin in the cell-wall makes it elastic, as in collenchyma.

As the cell-wall grows in thickness it undergoes chemical changes of various kinds with often many mineral matters introduced into it. Sometimes a cell-wall may remain as cellulose throughout its existence or it may be modified due to

chemical changes of cellulose or addition of new substances by the protoplasm or due to infiltration of foreign matter. The cell-wall thus may be impregnated with **lignin**, **cutin**, **suberin**, **mucilage**, or **mineral** matter. The changes that the cell-wall undergoes are:

1. **Lignification.** This is due to the deposit of layers of **lignin** in the original cellulose wall, or the cellulose may be converted into lignin. In either case the whole wall may be lignified, or lignification may only be partial. Lignin is a hard and chemically complex substance. It is found in the hard and woody tissues of plants. Lignified cells are usually thick-walled and dead. Although hard, lignin is permeable to water. The water-conducting vessels are all lignified. Most of the vegetable (textile) fibres are also lignified. Cotton fibres are, however, made of cellulose. The function of *lignified* tissues is mechanical, i.e. they contribute to the *rigidity* of the plant body.

Tests. (*a*) Acid **aniline sulphate** or **aniline chloride** solution turns *lignin* **bright yellow.** (*b*) Acid **phloroglucin** solution turns it **violet red.** (*c*) **Chlor-zinc-iodine** *stains it* **yellow.**

2. **Cutinization.** It is the transformation of cellulose or some of the pectoses into a substance, known as **cutin.** Cutin is waxy in nature. It forms a definite layer, called the **cuticle**, on the skin of the stem and the leaf. It makes the cell-wall impermeable or very slightly permeable to water. Its function is to prevent or check evaporation of water from the exposed surfaces of the plant.

3. **Suberization.** The cell-wall is often charged with a substance, called **suberin.** Suberization occurs in the walls of cork cells. The cells of the bottle cork are suberized. Suberin is a fatty substance and makes the cell-wall impervious to water and, therefore, like cutin, it also prevents or checks evaporation of water.

Tests for Cutin and Suberin. (*a*) **Iodine solution** followed by **sulphuric acid** *stains* both of them **yellowish brown.** (*b*) Both cutin and suberin are stained **brownish yellow** with **chlor-zinc-iodine.** (*c*) *Caustic* **potash** sol. (conc.) stains cutin **yellow** and suberin **brown,** the colour deepening on heating in both the cases; if this is followed by **chlor-zinc-iodine** they turn **violet.** *Cutin, however, resists the action of potash much better.* (*d*) When treated with **strong chlorophyll solution** *for an hour or so they turn* **deep green.** (*e*) When treated with **Sudan IV** *they turn red.*

4. **Mucilaginous Change.** Cellulose may also undergo change into a sort of slimy substance, known as **mucilage.** It absorbs water greedily, retains it tenaciously and forms a viscous mass; but when dry, it is very hard and horny. It is insoluble in alcohol. Mucilage is copious in the fleshy leaves

of Indian aloe (B. GHRITAKUMARI; H. GHIKAVAR). It is also abundant in the flowers of China rose, in the fruits of lady's finger, in the branches and leaves of Indian spinach (*Basella*, B. PUIN; H. POI), and in the seeds of linseed, *Plantago* (B. ISOBGUL; H. & P. ISOBGOL), *Lallemantia* (B. & H. TOPMARI), etc. Such seeds, when wetted, swell up and become mucilaginous. Mucilage also occurs in the fleshy leaves of desert plants.

Tests. (*a*) **Methylene blue** stains mucilage **deep blue**. (*b*) **Iodine solution** followed by **sulphuric acid** stains it **violet** (cf. cellulose)

5. **Mineralization.** Various mineral crystals (see pp. 198-200) may be introduced into the cell-wall; these substances are mostly formed in the body of the plant as a result of various chemical changes having taken place therein, and are deposited in the cell-wall or elsewhere in the form of crystals. Of these, silica or sand particles and calcium oxalate crystals are fairly common. Silica occurs most commonly in the leaves of grasses (see p. 189). Calcium oxalate crystals are widely distributed in plants (see pp. 199-200). Besides, in some plants, as in the leaf of India-rubber plant, calcium carbonate is deposited in the form of a crystalline mass looking like a bunch of grapes (see p. 199).

In the majority of fungi, and sometimes also in algae, the cell-walls are made up of a substance, called *chitin*—a substance allied to cellulose. *Chitin*, however, is peculiar to animals.

Micro-chemical Tests of the Cell-wall

Reagents	*Cellulose*	*Lignin*	*Cutin and Suberin*	*Mucilage*
1. Iodine solution ..	pale yellow	deep yellow	deep yellow	...
2. Chlor-zinc-iodine	blue or violet	yellow	yellowish brown	...
3. Iodine solution+ sulphuric acid or zinc chloride ...	blue	brownish	deep brown	violet
4. Aniline sulphate (acid)	...	bright yellow	...	...
5. Phloroglucin (acid)	...	violet red	...	...
6. Caustic potash sol. (conc.) ...	...	...	yellow and brown	...
7. Potash+chlor-zinc-iodine ...	...	...	violet	...
8. Chlorophyll sol....	...	...	green	...
9. Sudan IV ...	...	...	red	..
10. Methylene blue ...	...	...	...	deep blue

CELL INCLUSIONS

The chemical compounds that occur as non-living inclusions of plant cells are too varied to be enumerated here and, therefore, a short description of the commoner and more important ones only may be given. Some of these materials

are concerned in the *nutrition* of the protoplasm; some carry on a *special work*; there are others again, which are *not of any use* to the protoplasm. Accordingly, all these may be classified into three main groups, viz. (A) **reserve materials,** (B) **secretory products,** and (C) **waste products.**

A. Reserve Materials. These are substances manufactured by the protoplasm and stored up by it in particular cells. The various materials thus stored up are ultimately utilized by the protoplasm for its own nutrition as well as for the construction of the plant body. Thus the reserve materials constitute the *food* of plants. Many of these materials exist in solution in the cell-sap; others are deposited in solid form. The reserve materials include the various kinds of (I) ***carbohydrates,*** (II) **nitrogenous materials,** and (III) **fats and oils.**

I. **Carbohydrates.** These are substances containing carbon, hydrogen and oxygen. Of these, hydrogen and oxygen occur in the same proportion as they do in water. When these substances are heated they become charred, forming a black mass. This black mass is carbon. The water escapes and the carbon is left behind. Some carbohydrates are soluble in water; others are insoluble in it. Soluble ones are **sugars** and **inulin,** and the most important insoluble one is **starch.**

1. **Sugars.** There are various kinds of sugars occurring in plants. Of these, **grape-sugar** or **glucose** is chiefly found in grapes, and **cane-sugar** or **sucrose** in sugarcanes and beets. *Grape-sugar is the simplest of all carbohydrates and is formed* in the leaves by chloroplasts *in the presence of sunlight.* Other forms of carbohydrates are derived from it with or without the help of the living substance. *Glucose travels* in the plant body as such until it reaches the storage tissues, where it is mostly converted into starch, an insoluble carbohydrate, *and deposited for a shorter or a longer period.* This starch may again be converted into sugar. The chemical formula of grape-sugar is $C_6H_{12}O_6$, and that of cane-sugar $C_{12}H_{22}O_{11}$. Glucose contents of grapes are *12-15% or more,* of apples 7-10%, and of plums 3·5%; sucrose contents of sugarcanes 15-20%, and of beet roots *10-20%.*

Tests for Glucose. Add Fehling's solution or an alkaline solution of copper sulphate to it and boil, a yellowish red precipitate of cuprous oxide is formed.

Test for Sucrose. Boil sucrose solution with 1 or 2 drops of sulphuric acid, and then try the test for glucose.

2. **Inulin** (fig. 372). Inulin is a soluble carbohydrate, and occurs in solution in the cell-sap. Like starch it is easily converted into a form of sugar. Inulin is present in the tuberous roots of *Dahlia* and some other plants of *Compositae*. When pieces of *Dahlia* roots are steeped into alcohol or glycerine for 6 or 7 days, preferably more, inulin becomes precipitated in the form of spherical crystalline masses. A section is then prepared from one of the pieces and examined under the microscope. Inulin may also be precipitated by cutting rather thick sections from fresh material and keeping them in strong alcohol for about an hour. Under the microscope fully-formed inulin crystals are seen to be star- or wheel-shaped, and half-formed ones more or less fan-shaped. These crystals are deposited mostly across the cell-walls, and occasionally only in the cell-cavity. Sometimes these crystals are so large that they extend through many cells. Inulin has the same chemical composition as starch, viz. $(C_6H_{10}O_5)n$.

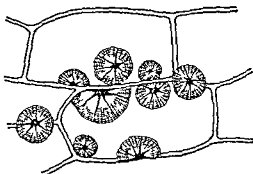


FIG. 372. Inulin crystals in the tuberous root of *Dahlia*.

Test. When inulin solution is treated with **acid phloroglucin** solution it turns **yellowish brown.** When precipitated, inulin is easily recognized by its peculiar form.

3. **Starch** (figs. 373-6). It is an insoluble carbohydrate and occurs in the form of minute grains. Starch grains are of



FIG. 373 FIG. 374 FIG. 375 FIG. 376

Starch Grains. Fig. 373. Simple eccentric grains in potato. Fig. 374. Compound grains in the same. Fig. 375 *a*, simple concentric grain in maize; *b*, ditto in pea. Fig. 376. *a*, compound grain in rice; *b*, ditto in oat.

universal occurrence in plants with the exception of fungi. *They occur in almost all parts of plants, but in storage tissues* they are specially abundant. Cereals and millets which constitute the staple food of mankind are specially rich in starch. When required for nutrition it is converted into sugar. Starch grains are of various forms: they may be *rounded and flat*, as in wheat; *polygonal*, as in maize; nearly *spherical*, as in pea and bean; or more usually *oval*, as in potato; or rarely *rod-* or *dumb-bell-shaped*, as in the latex cells (see fig. 412). They also vary very much in size, the largest known being about $\frac{1}{250}$ inch in length, as in the rhizome of *Canna*, and the smallest about $\frac{1}{5000}$ inch in length, as in rice. In potato they are of varying sizes. Starch is always derived from sugar, either in the leaf by the chloroplasts, called *assimilation starch*, or in the storage organ by the leucoplasts (or amyloplasts) called *storage starch*. Large and well-formed starch grains are always found in the storage organ.

In the starch grain a dark roundish spot, called the **hilum**, can be observed towards one end; it represents the point of origin of the grain. Around the hilum a variable number of layers or striations of different densities are alternately deposited. Each starch grain has thus a *stratified*



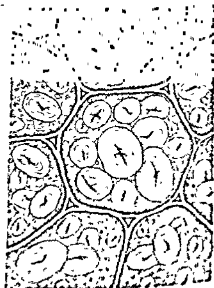


FIG. 377 FIG. 378

Starch Grains (*contd.*). Fig. 377. Section through a potato tuber showing a few cells with eccentric grains. Fig. 378. Section through a cotyledon of pea *showing* a few cells with concentric grains (and small granules of protein).

appearance. When the layers are laid down on one side of the hilum, as in potato, the grain is said to be **eccentric**, and when these are deposited concentrically round the hilum, as in wheat, maize, pea, bean and many pulses, the grain is said to be **concentric**. The former is more commonly met with than the latter. Starch grains may occur singly with one hilum, when they are said to be **simple**; sometimes, however, two or more grains occur together in a solid group with as many hila as there are grains in it; this group then is said to form a **compound** grain. It is seen that leucoplast simultaneously begins to secrete two or more grains very close to one another and subsequently as fresh layers are added to the grains these become pressed together into a mass; this mass is the compound grain; often the whole mass remains enveloped by a few common outer layers secreted by the leucoplast. Compound grains are found in sweet potato and in the endosperm of rice and oat (fig. 376); a few compound grains are also sometimes found in potato (fig. 374). Starch has the same chemical composition as cellulose and inulin, viz. $(C_6H_{10}O_5)n$. It is insoluble in water and alcohol. Rice contains 70-80% of starch; wheat about 70%; maize about 68%; barley 60-65%; arrowroot 20-30%; and potato 20%.

Test. It turns blue to black when treated with iodine solution, the density of the colour depending on the strength of the reagent.

Hemicellulose (see fig. 361). It is specially deposited as a thickening substance in the cell-walls of endosperm of date and other palms. It is stored up there as a reserve food material for the use of the embryo, and is often called **reserve cellulose**. When the seed germinates it becomes readily converted into sugar by the action of a digestive agent (enzyme) secreted by the cotyledon. In vegetable ivory-palm (*Phytelephas*) the reserve cellulose is very hard and is called vegetable ivory. Billiard balls are made from it. Hemicellulose is rather widely distributed in plants, as in stony fruits, seed-coats and woody tissues.

4. **Glycogen.** It is a very common form of carbohydrate occurring in fungi. In yeast (see fig. 599), a unicellular fungus it occurs to the extent of about 30% of the dry weight of the plant. It is not found in higher plants but is widely distributed among animals and is, therefore, sometimes called 'animal starch'. It occurs in the form of granules in the cytoplasm of the cell. Glycogen is a white amorphous powder and dissolves in hot water. It is coloured **reddish brown** with **iodine solution**. The colour disappears on heating and reappears on cooling. Its chemical formula is $(C_6H_{10}O_5)n$.

II. Nitrogenous Materials. The nitrogenous reserve materials that are stored up in plants for their use as food are the various kinds of **proteins** and **amino-compounds** (amines and amino-acids).

1. **Proteins.** Proteins are very complex, organic, nitrogenous substances containing carbon, hydrogen, oxygen and nitrogen.[1] More complex proteins also contain sulphur and phosphorus. Of all the organic compounds, with the exception of protoplasm, proteins are the most complex in their chemical composition, and there are various kinds of them found in the plant body. Some are soluble in water, but most of them are insoluble;

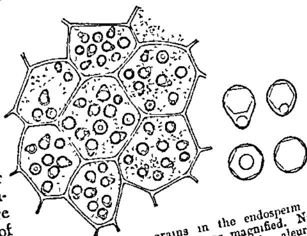


FIG 379 Aleurone grains in the endosperm of castor seed; *right*, a few grains magnified. Note the crystalloid and the globoid in the aleurone grains.

some are soluble in saline solution. All are, however, soluble in strong acids and alkalis. Proteins are found in plenty in the storage tissue, less so in active (growing) tissue, and they are practically absent from mature, inactive tissue. A common form of insoluble or sparingly soluble protein abundantly found in the endosperm of the castor seed is the **aleurone grain** (fig. 379). Each aleurone grain is a solid, ovate or rounded body, and encloses in it a crystal-like body, known as the **crystalloid**, and a rounded mineral body, called the **globoid**. The crystalloid occupies the wider part of the grain and is protein in nature, while the globoid occupies the narrower part and is a double phosphate of calcium and magnesium. The occurrence of crystalloid and globoid is not always constant in the aleurone grain. There may be one or more of them, or sometimes none at all. Aleurone grains vary in size. When they occur with starch they are very small, as in pea; but in oily seeds they are very much larger, as in castor.

Fatty seeds usually contain a higher percentage of proteins than starchy seeds, e.g. rice contains only 7% of proteins, wheat 12%, while sunflower seeds contain proteins as high as 30%. Starchy seeds of leguminous plants, however, contain as high a percentage of proteins as fatty seeds, e.g. in the pulses there is an average of about 25% of proteins; in soybean (*Glycine max*) protein contents vary from 42-47%.

[1] Average percentage composition may be given thus: carbon—50-54%; hydrogen—about 7%; oxygen—20-25%; nitrogen—16-18%; sulphur—0.4%; and phosphorus—0.4%.

Tests for Proteins. (1) Proteins are coloured yellowish brown with strong iodine solution. (2) **Xanthoproteic reaction**—add some strong nitric acid a white precipitate is formed; on boiling it turns yellow. After cooling add a little strong ammonia the yellow colour changes to orange (3) **Millon's reaction**—add Millon's reagent (nitrate of mercury) a white precipitate is formed; on boiling it turns brick-red. (4) **Biuret reaction**—an excess of caustic soda followed by a few drops of copper sulphate gives a violet colour which deepens on heating.

Aleurone grains may be studied in the following way. Prepare some thin sections through the endosperm of castor seed; treat them with 90% alcohol for 3-4 minutes and then with strong iodine solution. Mount a section in thick glycerine or olive oil and note under the microscope that the aleurone grains and the crystalloids turn deep brown, while the globoids remain colourless. Add 1% or 2% caustic soda solution to a fresh section and note that the aleurone grains get dissolved, while the globoids remain unaffected Treat another section with dilute acetic acid and see that only the globoids get dissolved.

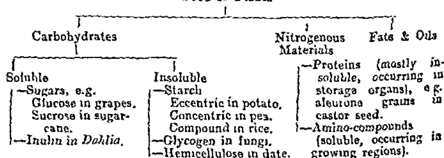
2. **Amino-compounds.** Amino-acids and amines are the *simplest forms of all nitrogenous food materials, and occur in* solution in the cell-sap. They are abundantly found in the growing regions of plants, less frequently in storage tissues. When translocation is necessary, proteins become converted into amines and amnio-acids. The amines and amino-acids *travel to the growing* regions where the protoplasm is very active, and these are directly assimilated by it. They are also the initial stages in the formation of complex proteins. They contain carbon, hydrogen, oxygen and nitrogen, and in the amino-acid, cystine, sulphur is also present..

III. Fats and Oils. Fats and oils occur to a greater or less extent in all plants. They occur in the form of minute globules in the protoplasm of the living cells. In the 'flowering' plants often special deposits of them are found in seeds and fruits. But in starchy seeds and fruits there is very little fat. Fats and oils are composed of carbon, hydrogen and oxygen, but the latter two do not occur in the same proportion as they do in water—the proportion of oxygen being always much less than in the carbohydrates. They contain no nitrogen. They are insoluble in water, but very readily soluble in ether, petroleum and chloroform. Comparatively *few of them are soluble in alcohol*, e.g. castor oil. Fats are synthesized in living bodies from fatty acids and glycerine under the action of the enzyme *lipase*. Both these products, viz. fatty acids and glycerine, are derived from carbohydrates (sugar and starch) during respiration. They form an important reserve food with a considerable amount of *energy* stored in them. Their energy value is more than double that of the carbohydrates. When fats are decomposed the energy stored in them is liberated and made use of by the protoplasm for its manifold activities. Digestion of fats into fatty acids

glycerine is also brought about by the enzyme *lipase*. Fats that are liquid at ordinary temperature are known as 'oils'. In plants fats are usually present in the form of oils. Oils are of two kinds, viz. *fixed or non-volatile*, as described above, and *essential or volatile* (see p. 197).

A large number of them are used for food, for manufacture of soap and oil-paints, for illumination, lubrication, etc., and are, therefore, of considerable economic importance, e.g. coconut oil olive oil, sesame or gingelly oil, castor oil, ground nut oil. linseed oil, mustard oil, cotton seed oil, etc.

Tests for Fats and Oils. (1) Osmic acid (1% aqueous solution) stains them black (2) Alcoholic solution of Sudan III, Sudan IV, or Sudan Red stains them red (3) Alcoholic solution of alkanet (or alkannin) stains them red, but the stain develops only after an hour or so.



B. Secretory Products. These include various products formed by the protoplasm, but not utilized by it for its nutrition and growth. They serve some particular functions in the plant, and are enumerated and described below:

1. **Enzymes.** These are soluble nitrogenous substances secreted by the protoplasm. Commonly they are known as the *digestive* agents, and their function is to render insoluble compounds soluble, e.g. starch into sugar, and complex compounds into simpler ones, e.g. sugar into carbon dioxide and water.

2. **Colouring Matters.** Of the various colouring matters *chlorophyll* and *anthocyanin* are the most important. Chlorophyll is mostly present in the leaves and is associated with the chloroplasts; food materials such as sugar and starch are manufactured with the help of chlorophyll. Anthocyanin occurs in solution in the petals of many flowers, and is responsible for the colour of the latter (see p. 181).

3. **Nectar.** Nectar is secreted by many flowers in special cells or glands to attract insects for pollination; the latter feed upon it, and incidentally carry the pollen grains from one flower to another (see pollination, p. 139).

C. Waste Products. These include various substances found in plants which are not of any vital use to the protoplasm, nor are they directly secreted by the latter, but are formed as a result of various constructive and destructive changes that are taking place in the body of the plant. They are, therefore, regarded as mere *by-products*. There being no excretory system in plants, these waste products are deposited in the bark, old leaves, dead wood, and in other special cells away from the sphere of protoplasmic activity. In this sense they may also be regarded as *excretions*. They may be (I) non-nitrogenous or (II) nitrogenous.

I. Non-nitrogenous

1. **Tannins.** These are a heterogeneous group of complex compounds widely distributed in plants. They commonly occur dissolved in the cell-sap, either in single isolated cells or in small groups of cells in almost all parts of the plant body. They are also found in the cell-walls, often abundantly in certain dead tissues, as in the bark and the heart-wood. In the leaves, young and old, and in many unripe fruits tannins are abundant. As the fruits ripen tannins disappear; they become converted into glucose and other substances. They are abundant in the fruits of myrobalans, e.g. chebulic myrobalan (B. HARITAKI; H. HARARA; P. HARRAR), beleric myrobalan (B. BAHERA; H. BHAIRAH; P. BAHIRA), emblic myrobalan (B. AMLA; H. AMLIKA; P. AMBLI). Tea leaves contain about 18 per cent of tannin. A very high percentage of tannin, varying from 25% to 75%, is present in the 'galls'. Catechu, a kind of tannin, is obtained from the heart-wood of *Acacia catechu*, and is also present in betel- or areca-nut. Tannin is a bitter substance, and that is why 'very strong' tea and fruits of myrobalans taste bitter. It is aseptic, i.e. free from the attack of parasitic fungi and insects. The presence of tannin makes the wood hard and durable. Tannins have a variety of uses. Mixed with iron salts they are used in the manufacture of ink. They are extensively used in tannery, i.e. converting hide into leather. They are also used for various medicinal purposes.

Tests. (*a*) They turn **blue-black** with an **iron salt** such as ferric chloride. (If a raw plantain be cut with a knife the latter is seen to turn black; this is due to the action of tannins, which the plantain contains, on the iron in the knife-blade.) (*b*) They are coloured **deep-brown** with chromic acid or protassium dichromate.

2. **Essential Oils.** These are volatile oils, and occur mostly in glands, known as *oil-glands* (see fig. 414). The transparent spots in the leaves of sacred basil, shaddock, lemon, lemon grass (*Cymbopogon*), *Eucalyptus*, etc., and those in the

rind of fruits like orange, lemon, shaddock, etc., are all oil-glands. These are also present in the petals of flowers of many plants, as in rose, jasmines, etc. The fragrant odour of such flowers is due to the presence of essential oils contained in them. They differ from fatty oils in their chemical composition as well as in being volatile. They are sufficiently soluble in water to impart to it their taste and odour. Being volatile, essential oils are obtained from plants by distillation, whereas fixed oils may be obtained by mere pressure. Like fatty oils, these are readily soluble in ether, petroleum, etc., and give the same tests (see below). They are soluble in alcohol, but fixed oils are not. There are some 200 essential oils of commercial value. Some of the common ones are lemon oil, eucalyptus oil, clove oil, lavender oil, sandalwood oil, thyme oil, etc.

Tests. These are stained **black** with **osmic acid**, and **red** with **alkannin**.

3. **Resins.** These are mostly found in the stems of conifers, and occur in abundance in special canals or ducts, known as *resin-ducts* (see fig. 391). They are yellowish solids, insoluble in water but soluble in alcohol, turpentine and spirit. When present in the wood, resins add to the strength and durability of it. These occur associated with a small quantity of turpentine which is removed by distillation, and the residue is pure resin.

Tests. *Resins are coloured* **red** with **alkannin.**

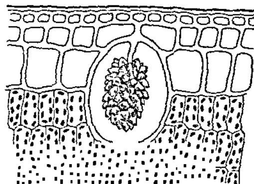
4. **Gums.** Gums are formed in various kinds of plants. They are insoluble in alcohol but soluble in water, readily swell up in it, and form a viscous mass. They are found in many phanerogamic plants, and are of various kinds. *Acacia senegal* yields the best gum-arabic of commerce. Gums also occur in mixtures with resins.

Tests. (*a*) **Iodine solution** stains gums **brown.** (*b*) **Iodine+sulphuric acid** stain them **bluish.** (*c*) A solution of copper sulphate (10%) and **caustic potash** (10%) stains gums **sky blue.**

5. **Mineral Crystals.** The common forms of crystals consist of silica, calcium carbonate and calcium oxalate. They occur either in the cell-cavity or in the cell-wall. Of them, crystals of calcium oxalate are most common, and are very widely distributed among various plants.

(1) **Silica** occurs as an incrustation on the cell-wall or it lies embedded in it. It is most frequently found in the leaves of grasses and in horsetail (*Equisetum*). Wheat straw contains about 72% of silica, rye straw about 50% and *Equisetum* about 71%.

(2) **Calcium carbonate** occurs in the outer layer (epidermis) of leaves of some plants, particularly in those of India-rubber plant, as a mass of small crystals. The inner wall near the surface protrudes inwards here and there in the form of a stalk, and this stalk becomes impregnated with a mass of small crystals of calcium carbonate, very much like a bunch of grapes suspended from a stalk. This crystalline mass of calcium carbonate is known as **cystolith** (fig. 380). Cystolith is also found in the leaves of banyan and in many plants of *Acanthaceae*.



Mineral Crystals FIG. 380 Cystolith in the leaf of India-rubber plant.

(3) **Calcium oxalate** occurs as crystals of various forms: (*a*) raphides, (*b*) conglomerate- or sphaero-crystals, and (*c*) octahedral and other forms.

(*a*) **Raphides** (figs. 381-3) are needle-like crystals occurring singly or in bundles. These are found in most of the plants in smaller or larger quantities, but are specially common in water hyacinth, aroids such as taro (*Colocasia*; B. KACHU; H. & P. KACHALU), *Amorphophallus* (B. OL; H. KANDA), etc., water lettuce (*Pistia*; B. PANA; H. JAL-KHUMBI), balsam (B. DOPATI;

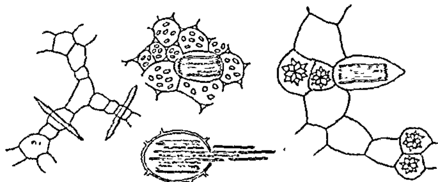


FIG. 381 FIG. 382 FIG. 383

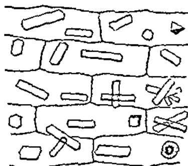
Mineral Crystals (*contd.*). Fig. 381. Solitary raphides (two) in the petiole of water hyacinth. Fig. 382. A bundle of raphides in the same; *bottom*, needles (raphides) shooting out. Fig. 383. Sphaero-crystals (four) and a bundle of raphides in taro (*Colocasia*).

H. GULMANDI), etc. They are frequently shut off by a cell-wall from coming in contact with the protoplasm.

(*b*) **Conglomerate crystals** or **sphaero-crystals** (fig. 383) ar clusters of crystals which radiate from a common centre, an hence have a more or less star-shaped appearance. They ar found in water lettuce (*Pistia*), taro (*Colocasia*), etc.

(c) **Octahedral, cubical, prismatic** and **rod-like crystals** (fig 384) of calcium oxalate are also common in plants; they ca be readily seen in the dry scales of onion.

Tests. (*a*) 50% nitric acid sol. (or hydrochloric or sulphuric acid) dissolves both calcium carbonate and oxalate crystals, but bubbles of carbo dioxide gas are evolved only in the case of carbonate crystals. (*b*) 30% acetic acid sol readily dissolves calcium carbonate crystals only, but not the oxalate crystals.


Mineral Crystals (*contd.*). FIG. 384. Various forms of calcium oxalate crystals in the dry onion scale.

6. **Latex.** It is the milky juice found in latex cells and latex vessels (see figs. 412-3). Latex occurs as an emulsion consisting of a variety of chemical substances. Among the nutritive materials sugars, starch grains (rod- or dumb-bell-shaped), proteins and oils are often found, and among the waste products gum, resin, tannin, alkaloids, rubber, etc., are common. Latex also contains some salts, enzymes, and often some poisonous substances. The function of latex is not clear; perhaps in some way it is associated with nutrition, healing of wounds and protection against parasites and animals. Latex is often white and milky, as in banyan, peepul, jack, madar, oleander, *Euphorbia*, etc., sometimes coloured (yellow, orange or red), as in opium poppy, prickly poppy, etc., or even watery, as in plantain.

7. **Organic Acids.** Living cells give an acid reaction. This is due to the presence of organic acids in the cell-sap. There are various kinds of such acids in plants, e.g. tartaric acid in tamarind, pine-apple and grape; citric acid in *Citrus* (e.g. lemon, orange and shaddock or pummelo); oxalic acid in wood-sorrel (*Oxalis*) and sorrel (*Rumex*); and malic acid in the leaves of gram and sprout leaf plant (*Bryophyllum*) and also in many unripe fruits. The sour taste of many fruits, particularly of unripe ones, is due to the presence of some such acids in them.

8. **Etiolin.** This is the decomposition product of chlorophyll. In the absence of light and for other causes chlorophyll

becomes decomposed into a pale-yellow pigment, known as etiolin.

II. Nitrogenous

Alkaloids. These are complex nitrogenous substances, and occur combined with some organic acids, mostly in seeds and roots of some plants. They have an intensely bitter taste and many of them are extremely poisonous. A few of them are liquids; majority of them are, however, crystalline solids which are insoluble or sparingly soluble in water, but readily so in alcohol. There are over 200 known alkaloids found in plants, of which a few may be mentioned here. These are quinine and cinchonine in *Cinchona*, nicotine in tobacco, morphine in opium poppy, caffeine in coffee and tea, strychnine in nux-vomica, atropine in deadly nightshade (*Atropa belladonna*), daturine in *Datura*, solanine in bitter-sweet (*Solanum dulcamara*; B. MITHA-BISH), and so on.

Occurrence, Use and Fate of Waste Products. Many of the waste products are ultimately deposited in the *bark and old leaves*. Remaining there, particularly in the bark, they prevent the attack of parasitic fungi and insects, and of grazing animals. When the bark and the leaves shed, the plant gets rid of the waste products. They also occur to a great extent in the *heart-wood*, and remain permanently stored up there. They make the heart-wood hard and durable, and free from insect and fungal attacks. Occurring in *seeds* and *fruits* they protect the embryo. Essential oils occurring in *flowers* attract insects for pollination, and when their function is over they are removed with the petals. Waste products present in *external glands and stinging hairs* prevent the attack of grazing animals. They may also occur more or less permanently in special *internal cells or glands*, and probably carry on no special function there. When gums and resins occur in excess in *special ducts, canals or cavities*, an exudation of them often takes place from the plant body.

[illegible] The cell-sap contains, dissolved in it, [illegible]retory products and waste products. [illegible] in soluble substances, it often contains [illegible]ystalline condition. (1) **Inorganic salts** such as chlorides, sulphates, nitrates and phosphates are always present in the cell-sap. (2) **Organic acids** such as oxalic, malic, citric, tartaric, etc., and various salts of them are fairly common in the cell-sap. (3) **Soluble carbohydrates** are specially common in the cell-sap, e.g. grape-sugar in grapes, cane-sugar in sugarcane, inulin in *Dahlia*, etc. (4) Of the nitrogenous materials soluble proteins, amines and amino-acids occur dissolved in the cell-sap, particularly in the cells of the growing regions and to some extent only in the storage cells. (5) Of the secretory products **anthocyanins** frequently occur in the petals of flowers and also in the young leaves of some plants. (6) In some plants mucilage may be found in the cell sap.

(7) Some of the waste products are also common in particular cells. These are **tannins, latex, alkaloids** and **glucosides.** Glucosides are substances which on decomposition give rise to a kind of sugar together with other products—which are chiefly aromatic. Common glucosides are saponin of soap-nut, indican of the indigo-dye, amygdalin of bitter almond, etc. Their use as reserve materials is definite only in some cases because of the sugar they contain. In many cases, however, glucosides are distinctly poisonous

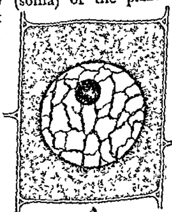
Inclusions of the Cytoplasm. Various kinds of solid particles and also some soluble substances are seen to be included in the body of the cytoplasm. Inclusions may be either living or non-living. Nucleus, plastids, centrosomes, chondriosomes and golgi bodies are living inclusions: while some of the reserve materials, secretory products and waste products are non-living inclusions Some of these inclusions are useful food substances, and some are only indirectly useful; while others are of no use to the plant, being mere waste products. All these are. (1) **food grains** such as starch grains and aleurone grains in green plants, and glycogen in fungi, (2) **oil-globules**—fats and oils, (3) **secretory products** such as enzymes, colouring matters (chlorophyll, carotin and xanthophyll), (4) **waste products** such as tannin, gum, resin, etc., (5) **mineral crystals** such as raphides, etc., and (6) **organic crystals** such as carotin, saponin, etc.

FORMATION OF NEW CELLS

Plants begin their existence as a single cell. This divides and forms two cells; these again divide, and the process continues until myriads of cells are formed. In such cases it is the nucleus that divides first, and the nuclear division is followed by the division of the cell. There are various other methods by which new cells are formed in plants.

I. By Division of Pre-existing Cells

1. **Somatic Cell Division.** Cell division leading to the development of the vegetative body (soma) of the plant is known as somatic cell division. It includes the division of the nucleus, called **mitosis** (*mitos*, thread) or **karyokinesis** (*karyon*, nut or nucleus) or **indirect nuclear division,** and the division of the cytoplasm, called **cytokinesis.**

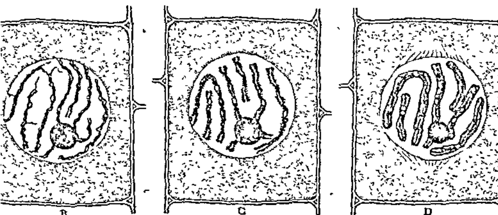


Mitosis. FIG. 385 *A*. Metabolic nucleus.

Mitosis (fig. 385). In this process the nucleus (A) passes through a complicated system of changes which can be studied in properly fixed and stained preparations of the root-tip or the stem-tip. The changes comprise four stages: *prophase, metaphase, anaphase and telophase.*

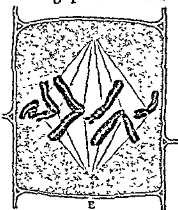
Prophase. The first sign of the prophase is the appearance of a number of separate, slender, crooked threads, called **chromosomes** (B). The chromosomes, particularly the longer

ones, are more or less spirally coiled. The individual chromosomes are always longitudinally double, with the two threads, called **chromatids,** remaining adpressed against each other throughout their length. Chromosomes are composed of nucleoproteins. As prophase proceeds the chromosomes relax their coils and thicken somewhat (C). Their double nature becomes more apparent. The outlines of the chromatids present a slightly irregular, hairy appearance. Soon, however, they lose their hairy appearance and become thicker and smoother. As prophase advances a chromosomal substance accumulates in a sheath or matrix round each chromosome and the chromatids become closely coiled in it (D). In well-fixed chromosomes some unstained gaps or con-



Mitosis (*contd.*). Fig 385 *B-D*. Prophase.

strictions are seen; these are the attachment regions, called **centromeres.** The nucleoli lose their staining power and disappear completely. The nucleus then rapidly passes into the next stage, the metaphase, through a complicated series of changes.

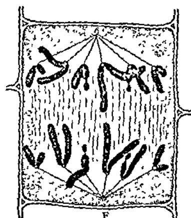


Mitosis (contd.)

Metaphase. The nuclear membrane disappears and a spindle-like body known as the **nuclear spindle** (usually bipolar, in some cases multipolar or even monopolar) is formed (E). The mode of origin of the spindle varies considerably. It may be formed entirely out of the nuclear sap, or, it may appear, commonly in root-
polar caps outsi
brane (as in D).

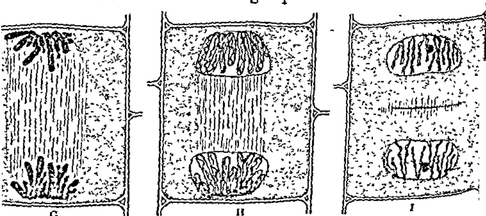
extends into the nuclear area. The chromosomes move to the equatorial plane of the spindle and stand there clearly apart from one another. At this stage the chromatids come even more closely together. From the centromeres of each pair of chromatids fibre-like extensions, called *tractile fibres*, are formed towards the opposite poles through the nuclear spindle. The number of chromosomes is normally constant for a particular species of plants and this number is also normally even, expressed as $2n$ (or $2x$) or diploid. Chromosome numbers cover a wide range but 24 seems to be a common figure.

Anaphase. At the end of the metaphase the centromeres of each pair of chromatids appear to repel each other. They diverge and move ahead towards the two opposite poles along the course of tractile fibres (F). The movement of the chromatids is autonomous. The causes of this movement are, however, not clearly understood. The chromatids soon become separated from each other. The spindle may also undergo elongation and thus help the complete separation of the two sets of chromatids.



Mitosis (*contd.*).
FIG. 385 *F*. Anaphase.

Telophase. At each pole the chromatids (now regarded as chromosomes) form a close group (G). The polar caps of the spindle disappear and a nuclear membrane is formed round each group of chromosomes (H).

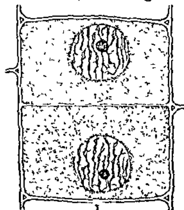


Mitosis (*contd.*). FIG. 385 *G-I*. Telophase.

Nucleoli reappear at definite points on certain chromosomes. The spindle body disappears and so does the matrix. The

chromosomes reorganize as two nuclei. The nuclear sap reappears and each nucleus increases in size (I). It passes into the metabolic stage or prepares for the next division.

Cytokinesis or *the division of the cytoplasm and the formation of the cell-wall.* Cytokinesis has recently been the subject of considerable investigations. The division of cytoplasm appears to take place in one of the two ways: by the formation of a new cell-wall in the equatorial region or by furrowing (i.e., by cleavage of the cytoplasm). The former process, known as the cell-plate method, is the usual one in vegetative division. It usually begins in the telophase when new cellulose particles are gradually deposited in the equatorial zone, and soon these particles fuse together to form a delicate membrane, dividing the cytoplasm into two new cells (J). In the latter process which is commonly seen during the formation of pollen grains in the anther (see fig. 247J) constrictions or furrows appear in the ectoplast and these gradually proceed within, dividing the cytoplasm into two parts.

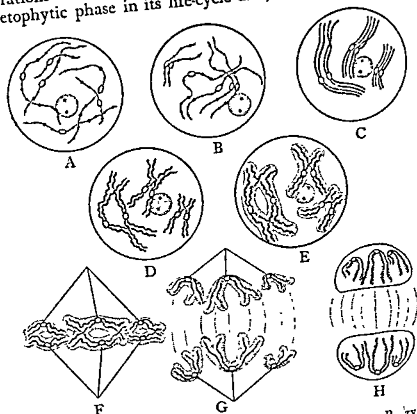


Mitosis (*contd.*). FIG. 385 *J*. Cytokinesis.

Importance. The importance of karyokinesis lies in the fact that by this complicated process of nuclear division, the constituents of the chromosomes are equally *apportioned to the two nuclei and thus the* daughter nuclei become qualitatively and quantitatively similar to the mother nucleus. Chromosomes are the bearers of hereditary characters and because of even distribution of chromosomal substance the two daughter nuclei possess all the characters and qualities of the mother nucleus.

2. **Meiosis or Reduction Division** (figs. 386A-B). Meiosis, first discovered by Strasburger in 1888, is a complicated process of nuclear division whereby the chromosome number is reduced to half (n) in the four nuclei so formed by this method. Supposing then that the mother nucleus bears 12 chromosomes ($2n$), each of the daughter nuclei will have only 6. Reduction division takes place in all sexually reproducing organisms at some time in their life-cycle. Sexual reproduction means the fusion of a male gamete with a female one resulting in the formation of a zygote from which the offspring develops in due course. Had the gametes contained the same number of chromosomes as their parents the offspring would have an increasing number of chromosomes apart from the peculiar composition of the latter, and in consequence the offspring would have developed into new, peculiar and distinct types

since chromosomes are the bearers of hereditary characters and meiosis is the mechanism for the transmission of these characters. Thus in all sexually reproducing plants and animals the gametes are haploid (n) to compensate for the chromosome doubling ($n+n=2n$) in the zygote as a result of fertilization. In higher plants showing an alternation of generations meiosis occurs as soon as a plant enters into the gametophytic phase in its life-cycle and, therefore, during the

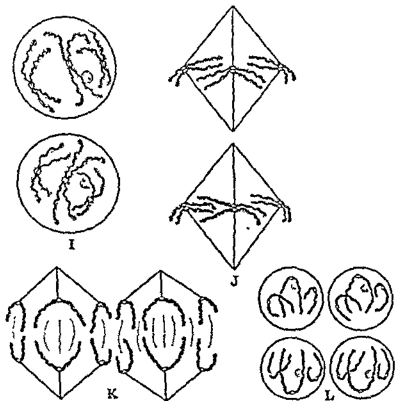


Meiosis. FIG. 386A. Division I. Prophase—*A*, leptotene; *B*, zygotene; *C*, pachytene; *D*, diplotene; *E*, diakinesis; *F*, metaphase; *G*, anaphase; *H*, telophase.

formation of spores from the spore-mother cell. In lower plants on the other hand meiosis occurs immediately after fertilization or on the germination of the zygote.

Process. Meiosis comprises two successive divisions of the mother nucleus (meiocyte) of which *division I* is the reduction division whereby the chromosome number is reduced to half (n), and *division II* is mitotic in nature. This being so, the four nuclei that are formed have the same reduced number (n) of chromosomes. **Division I** (fig. 386A). In this division also the nucleus passes through the same phases, as in mitosis, but there are certain special features of meiosis during the **prophase** which being a prolonged one has been subdivided into the following stages. *Leptotene* (A). At the early prophase the chromosomes appear as long and slender threads (each thread is a single chromatid and not double, as in mitosis). These

threads which are evenly distributed within the nucleus are seen to be present in identical pairs, i.e. for each thread there is a corresponding one similar to it in all respects, one being paternal and the other maternal. In each thread there is a definite number of granules known as **chromomeres** which appear like beads of various sizes. Leptotene actually represents the first appearance of chromosomes in the form of single slender threads in the diploid number. *Zygotene* (B). The identical chromosomes have a strong attraction for each other and they undergo pairing throughout their whole length. This pairing, called **synapsis**, is only in the nature of close lateral association but not their actual fusion. The pairing chromosomes are *homologous* to each other having been derived from the same parent chromosome. The chromosomes are now said to be in *bivalent* condition. Immediately after pairing the chromosomes begin to shorten and thicken. *Pachytene* (C) The paired chromosomes at this stage are distinctly shorter and thicker, and they are present in haploid number They split longitudinally, and four chromatids (two from each homologue) are produced. *Diplotene* (D) At this stage a sort of repulsive force (or loss of attraction) develops between the homologous pairs of chromosomes and they begin to separate from each other. They, however, remain connected at one point (usually in shorter ones) or more points (usually in longer ones); these points are known as **chiasmata.** At each chiasma the chromatids exchange corresponding portions by *crossing over*. This crossing over is a special feature



Meiosis (contd.). Fig. 266B. Division II. *I*, prophase; *J*, metaphase; *K*, anaphase; and *L*, telophase.

of meiosis. The chromosomes further shorten and thicken at this stage and present a coiling appearance in a sheath or matrix. They then pass on to the next stage. *Diakinesis* (E). At this stage the chromosomes further coil in the thick matrix, and assume their characteristic forms. They are also seen

to stand out clearly apart from one another within the nucleus, usually close to the nuclear membrane. **Metaphase (F).** The nuclear spindle develops and the chromosomes nucleolus disappear. The nuclear spindle develops and the chromosomes collect at the equator of the spindle. The four chromatids (in two pairs) are now attached to spindle fibres by two **centromeres** fairly apart from each other and facing opposite poles. **Anaphase (G).** The two pairs now separate from each other, possibly by a repulsive force, and move towards the opposite poles of the spindle along the course of the tractile fibres. **Telophase (H).** At the end of the anaphase the chromatid pairs (chromosomes) form a compact group at each pole. The two daughter nuclei, formed thus, contain haploid or (n) chromosomes, each with a pair of chromatids. Each nucleus then rests for a while or immediately passes on to **division II** (fig. 386B) which is mitotic in nature. In the prophase of this division the nucleolus reappears in each nucleus. The two chromatids of each chromosome, however, still remain separate and loose except at the chiasma. In the metaphase the chromosomes take up equitorial position in the newly formed spindle, and the paired chromatids are separated. In the anaphase the chromatids of each chromosome move apart towards the opposite poles of the spindle. In the telophase cytokinesis occurs and four nuclei are formed, each having one set of chromatids (now called chromosomes) reorganized in it.

3. **Amitosis or Direct Nuclear Division.** In this case the nucleus elongates to some extent and then it undergoes constriction, i.e. it becomes narrower and narrower in the middle or at one end, and finally it splits into two. The nuclei so formed are often of unequal sizes. The direct nuclear division may or may not be followed by the division of the cell. Amitosis is of frequent occurrence in the lower organisms like algae and fungi. In the higher plants it is seen to occur in old cells and in those showing distinct signs of degeneration.

4. **Free Cell Formation** (fig. 387). This is a modification of indirect nuclear division. It differs from the latter in that the cell-wall is not formed immediately after the division of the nucleus. In this process by repeated mitotic divisions a large number of nuclei are formed within the mother-cell. When the divisions of the nuclei cease, the cytoplasm aggregates round them, and a cell-wall is formed round each nucleus. The formation of the cell-wall gradually proceeds from one side to the other, resulting in a regular tissue (combination

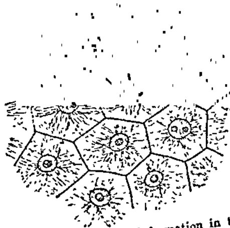


FIG. 387. Free cell formation in the development of endosperm.

of cells). The endosperm, i.e. the food storage tissue of the seed is formed by this method.

In some cases the nuclei divide by mitosis into a number of nuclei within the mother-cell. Protoplasm aggregates round each nucleus and this is followed by the formation of a cell-wall. Thus a number of small free cells, each enclosed by a wall, develop inside the mother-cell. This method is seen in the formation of ascospores (usually 8 in number) in ascomycetes (a group of fungi), the mother-cell itself being known as the ascus. Sometimes, the nuclear division is not followed by the formation of the cell-wall. Thus a number of free nuclei (naked cells) are seen within the mother-cell. This is seen in the formation of zoospores in many algae and fungi. In some cases, however, the nuclei divide very rapidly resulting in the formation of a large number of free nuclei within the mother-cell. The mother-cell quickly elongates and becomes branched, evidently containing those free nuclei within it. Such a structure is known as a **coenocyte**, and the latex cell (see fig. 412) and *Vaucheria* (see fig. 563) are common examples.

5. **Budding** (fig. 388). This is seen in yeast—a unicellular fungus. In this plant the cell forms one or more tiny outgrowths on its body. The nucleus undergoes direct divi-

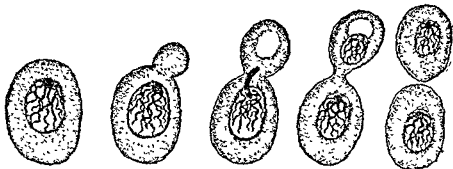


FIG. 388. Budding in yeast.

sion (amitosis) and splits up into two. One of them passes on to one outgrowth. The outgrowth increases in size and is ultimately cut off from the mother yeast as a new independent cell (a new yeast plant). This process of cell-formation is known as *budding*. Often budding continues one after the other so that chains and even sub-chains of cells (see fig. 598) are formed. Ultimately all the cells separate from one another.

II. By Fusion of Two Cells or Otherwise

1. **Rejuvenescence** (fig. 389). In rejuvenescence an old mass of protoplasm becomes young again. This is seen in the

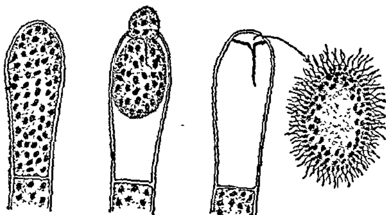


FIG. 389. Rejuvenescence in *Vaucheria*.

behaviour of zoospore in a green alga, known as *Vaucheria*. In the formation of the zoospore the protoplasmic contents withdraw from the cell-wall, contract into a mass, and escape from the mother-cell through an apical opening caused by the bursting of the wall. After escape the protoplasmic mass or zoospore produces numerous cilia arranged in pairs all over its body and then by the vibration of these cilia it freely swims about in water for a while (half an hour or less). Thereafter it comes to rest. All the cilia are withdrawn and a regular cell-wall is formed. It undergoes a period of rest and germinates later. Since the protoplasm rejuvenates, i.e. becomes young and active, taking on a new lease of life, the process is known as *rejuvenescence*.

2. **Conjugation.** This consists in the fusion of two reproductive units, called gametes, which are *similar* to each other in all respects, as in *Spirogyra* (see fig. 549) and *Mucor* (see fig. 586). As a result of this fusion a new cell, called the zygospore, is formed. It gives rise to a new plant.

3. **Fertilization.** This consists in the fusion of two *dissimilar* reproductive units or gametes which can be distinguished as *male* and *female*. The resulting cell is a perfectly new one. The new cell which is the result of fertilization is known as the oospore. It gives rise to a new plant. Fertilization is the commonest sexual mode of reproduction in plants (see fig. 301).

Note that the product of fusion of two reproductive units or gametes goes by the name of **zygote**. The zygote is called **zygospore** in the case of conjugation, as in lower algae and lower fungi, and it is called **oospore** in the case of fertilization, as in all higher plants.

Vessels, Intercellular Spaces and Cavities

Vessels. Sometimes it is only the cross-walls of a cylindrical row of cells that get dissolved, and consequently a large opening is formed, side or longitudinal walls remaining intact. The constituent cells thus together give rise to a tube- or pipe-like structure. This pipe-like structure without partition walls is known as the **vessel** (fig. 390). The ends of the constituent cells, or vessel segments, are mostly narrow with the perforation oblique (see figs. 408-9). Vessels are of different kinds. They are thick-walled, lignified and dead. Lignin is deposited as a thickening material on the inner surface of the side-walls in various patterns, and according to the mode of thickening (see p. 184) vessels may be of the following types—**annular, spiral, scalariform, reticulate,** and **pitted** (see figs. 404-9). Vessels are carriers of water and raw food materials, i.e. they conduct these substances from the root to the leaf. Being thick-walled and lignified they also serve to give strength to the plant body.

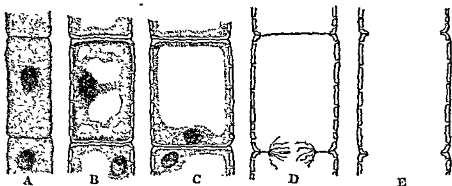


FIG. 390. Development of vessel. *A-E* are stages in its development.

Intercellular Spaces. When the cells are young they remain closely packed without any empty space or cavity between them; but as they grow, their walls split at certain points, giving rise to small cavities or empty spaces; these are intercellular spaces. They remain filled with air or water.

Schizogenous Cavities. Bigger cavities are also often fo[rmed] by the splitting up of common walls and the separation

masses of cells from one another: these are schizogenous (*schizein*, to split) cavities. Intercellular spaces and these cavities form an intercommunicating system so that gases and liquids can easily diffuse from one part of the plant body to the other. Most resin-ducts in plants are schizogenous cavities (fig. 391).



FIG. 391. Resin-duct of pine stem with resin.

Lysigenous Cavities. Sometimes, during the development of a mass of cells, their walls break down and dissolve, and as a consequence large irregular cavities appear; these are known as **lysigenous** (*lysien*, to break down) cavities. These cavities are meant to store up water, gases, essential oils, etc., and thus act as glands (see fig. 414).

CHAPTER II

THE TISSUE

Cells grow and assume distinct shapes to carry on definite functions. Cells of the same shape grow together and combine into a group for the discharge of a common function. Each group of mature cells gives rise to a tissue. *A tissue is thus a group of cells or of vessels alike in form and function and similar in origin.* Tissues may primarily be classified into two groups: **meristematic** and **permanent.**

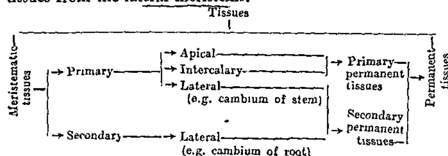
Meristematic Tissues (*meristos*, to divide). These are composed of cells that are in a state of division or retain the power
, oval or polygonal
ieir walls thin and
d active with large
nuclei; and the vacuoles small or absent. According to their origin meristems may be **primary** or **secondary.**

The **primary meristem** persists from the earliest stage of development of an organ of a plant, and according to its position may be **apical, lateral,** or **intercalary.** (a) The apical meristem lies at the apex of the stem and the root. (b) The intercalary meristem, when present, lies between masses of

permanent tissues, either at the base of the leaf, as in pine, or at the base of the internode, as in some grasses, horsetail (*Equisetum*), etc., or sometimes below the node, as in mint; it is a detached portion of the apical meristem separated from the latter due to growth of the organ. The apical meristem, and also the intercalary meristem when present, give rise to *primary permanent tissues*, and are responsible for increase in length of the plant body. (*c*) The lateral meristem, e.g. the cambium of the stem, lies along the side of the stem. It divides mainly in one plane in the radial direction, gives rise to *secondary permanent tissues*, and is responsible for growth in thickness of the plant body.

The **secondary meristem,** on the other hand, appears later
at a certain stage of develo
always lateral lying along
It is seen that some of the
meristematic, i.e. they acq
stitute the secondary meris
the interfascicular cambium
The secondary meristem is always lateral. All lateral meristems (primary and secondary) give rise to *secondary permanent tissues*, and are responsible for growth in thickness of the plant body.

Permanent Tissues. These are composed of cells that have lost the power of dividing, having attained their definite form and size. They may be living or dead and thin-walled or thick-walled. Permanent tissues are formed by differentiation of the cells of the meristems and may be **primary or secondary.** The primary permanent tissues are derived from the apical meristems of growing regions and the secondary permanent tissues from the lateral meristems.



Note. The **primary growth** of the plant is due to enlargement of the cells of the primary permanent tissues which have been differentiated from the apical meristems (root-apex and stem-apex), and this is the same in both dicotyledons and monocotyledons. The **secondary growth,** on the other

hand, is due to the formation of new (secondary) permanent tissues which have been cut off by lateral meristems such as the different cambial layers. In dicotyledons and gymnosperms the cambium is present, and by its activity the secondary growth takes place in these cases; while *in monocotyledons there is no cambium* and hence no secondary growth.

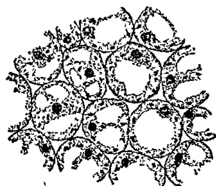
CLASSIFICATION OF PERMANENT TISSUES

In their earlier stages the cells are more or less similar in structure, but as the division of labour increases they gradually assume various forms and give rise to permanent tissues. These may be classified as *simple* and *complex*. A simple tissue is made up of one type of cells forming a homogeneous or uniform mass, and a complex tissue is made up of more than one type of cells working together as a unit. To these may be added another kind of tissue—the secretory tissue.

I. Simple Tissues

1. **Parenchyma** (fig. 392). Parenchyma consists of a collec-

Fig. 392.



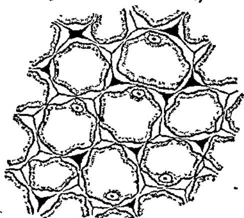


Fig. 393

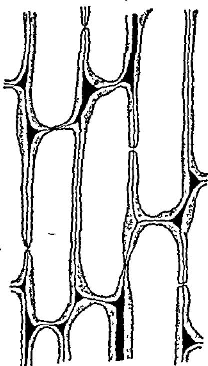


Fig. 394

Fi[illegible] in transection.
[illegible]section.

tion of [illegible], that is, *equally*

expanded on all sides. Typical parenchymatous cells are oval, spherical or polygonal in shape. Their walls are thin and made of cellulose; they are usually living. Parenchymatous tissue is of universal occurrence in all the soft parts of plants. Its function is mainly storage of food material. When parenchymatous tissue contains chloroplasts it is called *chlorenchyma*; its function is to manufacture food material. A special type of parenchyma develops in many aquatic plants and in the petiole of *Canna* and banana. The wall of each such cell grows out in several places like rays radiating from a star and is, therefore, stellate or star-like in general appearance. These cells leave a lot of air cavities between them, where air is stored up. Such a tissue is often called *aerenchyma* (figs. 395-6).

2. **Collenchyma** (figs. 393-4). This tissue consists of somewhat elongated parenchymatous cells with oblique, slightly rounded or tapering ends. The cells are much thickened at the corners against the intercellular spaces. They look circular, oval or polygonal in a transverse section of the stem. The thickening is due to a deposit of cellulose impregnated with pectin; although thickened, the cells are never lignified. They are provided with simple pits here and there in their walls. Collenchyma is found under the skin (epidermis) of herbaceous dicotyledons, e.g. sunflower, gourd, etc., occurring there in a few layers with special development at the ridge, as in gourd stem. It is absent from the root and the monocotyledon except in special cases. The cells are living and often contain a few chloroplasts. Being flexible in nature

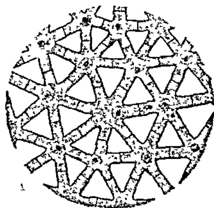


FIG. 395

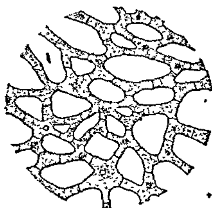


FIG. 396

FIG. 395. *Aerenchyma* in the petiole of banana. FIG. 396. The same in the petiole of *Canna*.

collenchyma gives tensible strength to the growing organs, and being extensible it readily adapts itself to rapid elongation of

the stem. Containing chloroplasts *it does* also manufacture sugar and starch. Its functions are, therefore, both mechanical and vital.

3. **Sclerenchyma** (fig. 397). Sclerenchya (*scleros*, hard) consists of very long, narrow, thick and lignified cells, usually pointed at both ends. They are fibre-like in appearance, and hence they are also called sclerenchymatous fibres, or simply fibres. Their walls often become so much thickened that the cell-cavity is nearly obliterated. They have simple, *often oblique, pits in* their walls. The middle lamella is conspicuous in sclerenchyma. Sclerenchymatous cells are abundantly found in plants, and occur in *patches* or *definite* layers which are seen to dovetail into each other in the *longitudinal direction*. *Sometimes* also they occur *singly among* other cells. They are dead cells, and serve a purely mechanical function, that is, they give strength and rigidity *to the* plant body and thus enable it to withstand various *strains*. Their average length is *1 to 3 mm.* in angiosperms, *and 2* to 8 mm. in gymnosperms. In *special cases*, as in hemp (*Cannabis*; B. & H. GANJA), rhea (*Boehmeria nivea*), flax (*Linum*), etc., the fibres are of excessive *lengths ranging from 20 mm. to 550* mm. Such long, thick-walled cells make excellent textile fibres of commercial importance. Other common plants yielding long fibres are jute, coco-nut, Indian hemp (*Crotalaria juncea*; B. SHONE; H. & P. SAN), *Madras* hemp (*Hibiscus cannabinus*), sisal hemp (*Agave sisalana*), bowstring

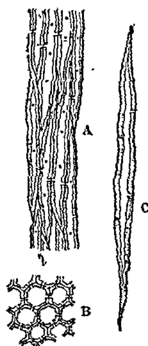


Fig. 397



Fig 398

Fig. 397. Sclerenchyma; *A*, fibres as seen in longi-section; *B*, the same as seen in transection; and *C*, a single fibre. Fig. 398. Stone cells; *A*, as seen in transection; *B*, as seen in longi-section.

hemp (*Sansevieria* ; B. MURGA ; H. MARUL), rozelle (*Hibiscus sabdariffa* ; B. MESTA ; H. PATWA), etc.

Sometimes here and there in the plant body special types of sclerenchyma may be developed. These are known as the **stone** or **sclerotic cells** (also called **sclereids** ; fig. 398). The cells though very thick-walled and strongly lignified are not long and pointed, but are mostly isodiametric or irregular in shape or slightly elongated. They are dead and have a very narrow cell-cavity, and their walls are provided with many simple pits which are branched or unbranched. Stone cells may be somewhat loosely arranged or closely packed, and occur in hard

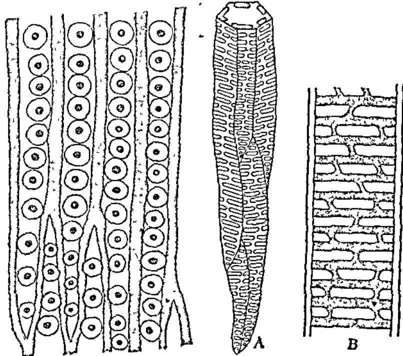


FIG 399 FIG. 400
Tracheids. Fig. 399. Tracheids of pine stem (in radial section) with bordered pits. Fig. 400. *A*, a scalariform tracheid of fern; *B*, a portion of the wall of the same magnified.

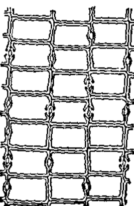
seeds, nuts and stony fruits. They contribute to the firmness and hardness of the part concerned. Groups of stone cells may also be found among masses of parenchyma in the stem or the leaf or the fruit. The flesh of pear is gritty because of the presence of stone cells in it.

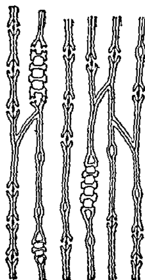
II. Complex Tissues

1. **Xylem.** Xylem or wood is a conducting tissue and is composed of elements of different kinds, viz. (*a*) tracheids, (*b*)

vessels or tracheae (sing. trachea), (*c*) wood fibres and (*d*) wood parenchyma. Xylem as a whole is meant to conduct water and mineral salts upward from the root to the leaf, and to give mechanical strength to the plant body.

(*a*) **Tracheids** (figs. 399-403). These are elongated, tube-like cells with hard, thick and lignified walls and large cell-





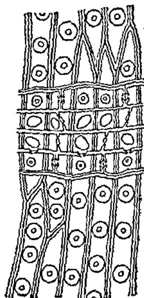


FIG. 401 FIG. 402 FIG. 403

Tracheids with bordered pits. Fig. 401. Pine stem in transection. Fig. 402. The same in tangential (longitudinal) section. Fig. 403. The same in radial (longitudinal) section.

cavity. Their ends are tapering, either rounded or chisel-like, less frequently pointed. They are dead, empty cells with their walls provided with one or more rows of bordered pits. Tracheids may also be annular, spiral, scalariform or pitted (with simple pits). In transverse section they are mostly angular, either polygonal or rectangular. Tracheids (and not vessels) occur alone in the wood of ferns and gymnosperms, whereas in the wood of angiosperms they occur associated with the vessels. Their walls being lignified and hard, tracheids give strength to the plant body but their main function is conduction of water from the root to the leaf.

(*b*) **Vessels or Tracheae** (figs. 404-9). Vessels are cylindrical, tube-like structures; they are formed of a row of cells placed end on end, from which the transverse partition walls are absorbed (see p. 211). A vessel or trachea is thus a tube-like series of cells, very much like a series of water pipes forming a pipe line. Their walls are thickened in various

ways, and according to the mode of thickening vessels have received their names such as annular, spiral, scalariform, reticulate, and pitted. Associated with the vessels are often

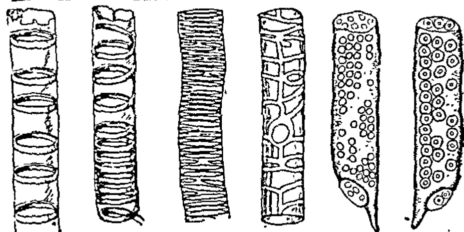


FIG. 404 FIG. 405 FIG. 406 FIG. 407 FIG. 408 FIG. 409
-Kinds of Vessels. Fig. 404. Annular. Fig. 405. Spiral. Fig. 406. Scalariform. Fig. 407. Reticulate. Fig. 408. A vessel with simple pits. Fig. 409. A vessel with bordered pits.

found some tracheids. Vessels and tracheids form the main tissues of the wood or xylem of the vascular bundle (see fig. 429). They serve for conduction of water and mineral salts from the roots to the leaves. They are dead, thick-walled and lignified, and as such they also serve the mechanical function of strengthening the plant body.

Note, that a tracheid is a regular cell with lateral and transverse walls intact; while a trachea is a true vessel with transverse walls dissolved and, therefore, tube-like in appearance. Both are thick-walled and lignified, and both may be annular, spiral, scalariform, reticulate or pitted.

(c) **Wood Fibres.** Sclerenchymatous cells associated with *wood or xylem are known as wood fibres. They occur abund*antly in woody dicotyledons and add to the mechanical strength of xylem and of the plant body as a whole.

(d) **Wood Parenchyma.** Parenchymatous cells are of frequent occurrence in xylem, and are known as wood parenchyma. The cells are alive and generally thin-walled. The *wood parenchyma assists, directly or indirectly, in the conduction* of water upwards through the vessels and the tracheids; it also serves for food storage.

2. **Phloem.** Phloem or bast is another conducting tissue, and is composed of t ...s,
(b) **companion cells,** (c) ...es
(rarely). Phloem as a ...d

materials from the leaf to the storage organs and the growing regions.

(*a*) **Sieve-tubes** (figs. 410-1). Sieve-tubes are slender, tube-like structures, and are composed of elongated cells, placed end on end. Their walls are thin and made of cellulose; the transverse partition walls are, however, perforated by a number of pores. The transverse wall then looks very much like a sieve, and is called the **sieve-plate.** The sieve-plate may sometimes be formed in the side (longitudinal) wall. In some cases the sieve-plate is not transverse (horizontal), but inclined obliquely, and then different areas of it become perforated. The sieve-plate of this nature is said to be a *compound plate*. At the close of the growing season the sieve-plate is covered by a deposit of a colourless, shining substance in the form of a pad, called **callus** or **callus pad.** This consists of a carbohydrate, called *callose*. In winter the callus completely clogs the pores; but in spring, when the active season begins, it gets dissolved. In old sieve-tubes callus forms a permanent deposit. The sieve-tube contains no nucleus, but has a lining layer of cytoplasm which is continuous through the pores. Sieve-tubes are used for the longitudinal transmission of prepared food materials—proteins and carbohydrates—from the leaves to the storage organs and the growing regions of the plant body. A heavy deposit of

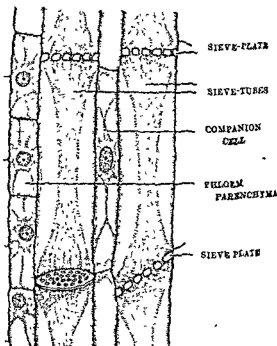


FIG. 410. Sieve tissue in longitudinal section.

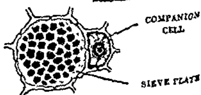


FIG. 411. Sieve tube in transection.

food material is found on either side of the sieve-plate with a narrow median portion.

(*b*) **Companion Cells.** Associated with each sieve-tube and connected with it by pores there is a thin-walled, elongated cell, known as the **companion cell.** It is living, containing protoplasm and an elongated nucleus. The companion cell is present only in angiosperms.

(*c*) **Phloem parenchyma.** There are some parenchymatous cells in the phloem. These are living, and in shape often cylindrical. Phloem parenchyma, is, however, absent in many monocotyledons.

(*d*) **Bast Fibres.** Sclerenchymatous cells occurring in the phloem or bast are known as bast fibres. These are generally absent in the primary phloem but are of frequent occurrence in the secondary phloem.

III. Secretory Tissues

1. **Laticiferous Tissue.** This consists of thin-walled, greatly elongated and much branched ducts (figs. 412-3) containing a milky juice, known as *latex* (see p. 200). Laticiferous ducts are of two kinds: latex vessels and latex cells. They

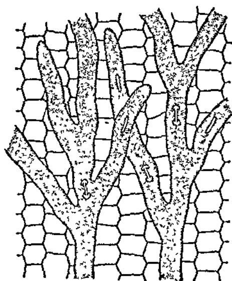


Fig. 412

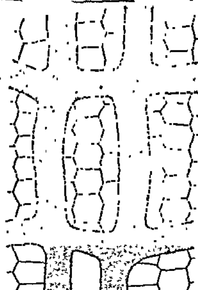


Fig. 413

Laticiferous Tissue. Fig. 412. Latex cells. Fig. 413. Latex vessels

contain numerous nuclei which lie embedded in the thin layer of protoplasm lining the cell-wall which is usually thin and made of cellulose. They occur irregularly distributed in the mass of parenchymatous cells. The function of latici-

ferous ducts is not clearly understood. They may act as food-storage organs or as reservoirs of waste products. They may also act as translocatory tissues.

Latex vessels (fig. 413) are the result of fusion of many cells. They are formed from rows of elongated meristematic cells from which partition walls soon get dissolved, as in wood vessels. They grow more or less as parallel ducts, and in the mature portion of the plant they anastomose with one another *by the fusion of their branches, forming a network.* Latex vessels are found in poppy family, e.g. opium poppy, garden poppy and prickly poppy, and also in some species of sunflower family or *Compositae*, e.g. *Sonchus.*

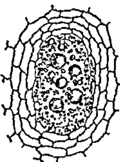
Latex cells (fig. 412), on the other hand, although much branched like the latex vessels, are really single or independent units. They originate as minute structures and then with the growth of the plant elongate and branch, ramifying in all directions through the tissues of the plant, but *without fusing together to form a network.* They are coenocytic in nature (see p. 209). Latex cells are found in madar (*Calotropis*), spurges (*Euphorbia*), oleander (*Nerium*), yellow oleander (*Thevetia*), periwinkle (*Vinca*), *Ficus* (e.g. banyan, fig, peepul), etc.

Latex cells may be isolated and studied in the following way. Slice off a big portion of the pith from a piece of *Euphorbia neriifolia* stem. Break transversely the cortical portion of the stem with a light incision on its surface and then pull it apart. Some slender threads will be seen to come out. Mount them carefully in the usual way and examine under the microscope. A number of elongated, tubular, branched cells will be clearly seen. These are the latex cells. By irrigating with iodine solution rod and dumb bell-shaped starch grains may be distinctly seen in the latex cells. A longitudinal section through the stem will, however, show that the latex cells lie embedded in parenchyma, as shown in fig. 412.

2. **Glandular Tissue.** This tissue is made of **glands** which are special structures containing some secretory or excretory products. Glands may consist of single isolated cells or small groups of cells with or without a central cavity. They are of various kinds and may occur as external glands on the skin layer (epidermis) or as internal glands lying embedded in other tissues in the interior of the plant body. They are parenchymatous in nature, and contain abundant protoplasm with a large nucleus. They contain different substances and carry on manifold functions. Glands, as said above, may be internal or external.

Internal glands are (1) oil-glands (fig. 414) secreting essential oils, as in the fruits and leaves of orange, lemon, pummelo, etc.; (2) mucilage-secreting glands,, as in the betel leaf;

(3) glands secreting gum, resin, tannin, etc.; (4) digestive glands secreting enzymes or digestive agents; and (5) water-secreting glands, known as **hydathodes.**







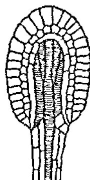


Fig. 414 Fig. 415 Fig. 416 Fig. 417

Glands. Fig. 414. An oil-gland of orange rind. Fig. 415. A glandular hair of *Boerhaavia* fruit Fig. 416. A digestive gland of butterwort. Fig. 417. A digestive gland of sundew.

Hydathodes (fig. 418) are special structures through which exudation of water takes place in liquid form. They are mainly found in aquatic plants and in moist places. They occur at the tip of t ices of veins and are made of a group o ercellular spaces filled with water, but few present cells, called *epithem cells*, open out into one or more sub-epidermal chambers; these in turn communicate with the exterior through an open water stoma or water pore. The water stoma structurally resembles an ordinary st la m in water lettuce (*Pistia*), water hyacinth, garden nasturtium, aroids, many grasses, etc.

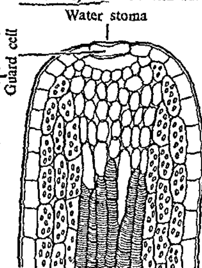
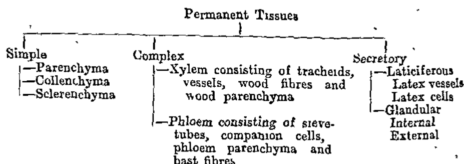


Fig. 418. Hydathode of water lettuce (*Pistia*).

External glands occur as outgrowths and are in the nature of short hairs tipped by glands, known as glandular hairs. External glands are: (1) water-secreting hairs or glands, also called hydathodes; (2) glandular hairs (fig. 415) secreting gummy substances, as in tobacco, *Plumbago* (B. CHITA; H. & P. CHITRAK), and *Boerhaavia* (B. PUNARNAVA; H. THIKRI); (3) glandular hairs secreting irritating, poisonous substances, as in nettles (fig. 181); (4) honey glands

or nectaries, as in many flowers; and (5) enzyme-secreting glands (figs. 416-7), as in carnivorous plants.



Distribution of Strengthening or Mechanical Tissues. The distribution of mechanical tissues in the plant body is determined by several factors. From a purely mechanical standpoint the principle of distribution is as follows. Stems have to bear the weight of the upper parts, and are swayed back and forth by the wind. They are, therefore, subjected to alternate stretching and compressing. The best position for strengthening tissues in stems, therefore, is close to the periphery, either in the form of a cylinder or in patches. Roots, on the other hand, are subjected to the pulling force exerted by the swaying stem and also to the compressing force exerted by the surrounding soil. These forces are met by roots by the development of solid wood cylinder in or around the centre.

Collenchyma and sclerenchyma including fibres, wood fibres, and bast fibres are the two most important tissues concerned in the strengthening of the plant body. Of these the distribution of collenchyma has been already discussed (see p. 215). In stems sclerenchyma is distributed in various parts. It may occur as (1) hypodermis, particularly in woody dicotyledons, many monocotyledons and ferns; (2) isolated strands in the cortex, as in the palm stem; (3) a few definite layers in the pericycle, as in the *Cucurbita* stem; (4) irregular patches in the pericycle; (5) patches lying associated with the phloem of the vascular bundle, and constituting the hard bast, as in the sunflower stem; (6) a continuous zone extending from one vascular bundle to another, as often seen in lily family or *Liliaceae*; (7) wood fibres associated with wood or xylem; (8) bast fibres, more particularly in secondary phloem; and (9) bundle sheath encircling a vascular bundle, as in many monocotyledons.

Roots less frequently develop sclerenchyma, and they are wanting in collenchyma. Here the lignified wood vessels and

tracheids give the necessary strength. Later on wood fibres develop in the secondary wood and contribute materially to the mechanical strength of the root. In some dicotyledonous roots, as in broad bean (*Vicia*), hard bast is present. In many monocotyledonous roots, as in aroids, the pith is sclerenchymatous. Sometimes, as in orchids, the conjunctive tissue is also sclerenchymatous.

For distribution of sclerenchyma in the leaf see p. 260.

PRIMARY (APICAL) MERISTEM

I. Stem Apex (fig. 419). A median longitudinal section through the apex of a stem, when examined under the microscope, shows that the apical meristem or growing region is composed of a small mass of usually rounded cells which are all essentially alike and are in a state of division; these meristematic cells constitute **promeristem** (or primordial meristem). The cells of the promeristem soon differentiate into three regions, viz., dermatogen, periblem and plerome. The cells

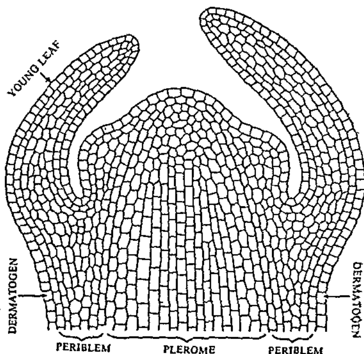


FIG. 419. Stem apex.

of these three regions grow and give rise to primary permanent tissues in the mature portion of the stem. The section further shows on either side a number of outgrowths which arch over the growing apex; these are the young leaves

of the bud, which cover and protect the tender growing apex of the stem.

1. **Dermatogen** (*derma*, skin; *genes*, to produce). This is the single outermost layer of cells. It passes right over the apex and continues downwards as a single layer. The cells divide by *radial* walls only, i.e. at right angles to the surface of the stem and increase in circumference, thus keeping pace with the increasing growth in volume of the underlying tissues. The dermatogen gives rise to the skin layer or epidermis of the stem.

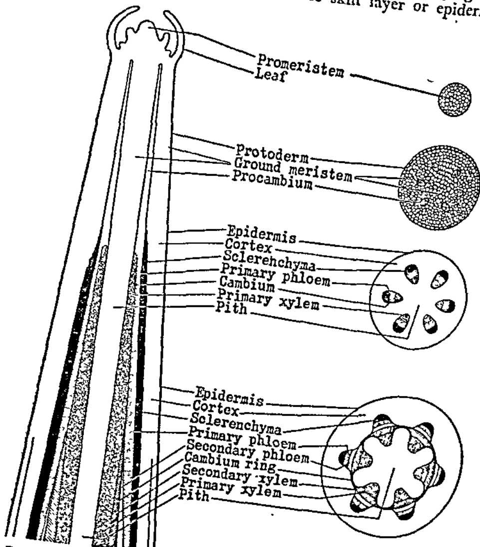


FIG. 420. Stem apex showing primary meristems and differentiation of tissues.

2. **Periblem** (*peri*, around; *blema*, clothing or covering). This lies internal to the dermatogen, and is the middle region

of the apical meristem. At the apex it is single-layered but lower down it becomes multi-layered. It forms the cortex of the stem, which is often, particularly in dicotyledons, differentiated into hypodermis, general cortex and endodermis.

3. **Plerome** (*pleres*, full). It lies internal to the periblem, and is the central region of the stem apex. At a little distance behind the apex certain groups or strands of cells show a tendency to elongate. These groups or strands of elongated cells are said to form the **procambium.** The procambial strands ultimately become differentiated into bundles of vessels and sieve-tubes, i.e. into vascular bundles. A portion, however, remains undifferentiated, and it forms the cambium of the vascular bundle. Plerome is differentiated into the pericycle, medullary or pith rays, pith and the vascular bundles (derived from the procambial strands), and forms the central cylinder or *stele* of the stem.

II. Root Apex (fig. 421). A median longitudinal section through the apex of the root shows that it is covered over and protected by a many-layered tissue which constitutes the **root-cap.** The apical meristem or growing region lies behind the root-cap (see fig. 24). The promeristem, as in the stem, early differentiates into three regions, viz. (1) dermatogen, (2) periblem, and (3) plerome. In many roots, however, these three regions are not clearly marked.

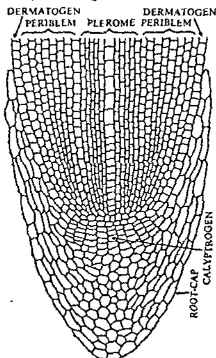


FIG. 421. Root apex.

1. **Dermatogen.** As in the stem, it is also single-layered here, but at the apex it merges into the periblem; just outside this the dermatogen cuts off many new cells, thus forming a small-celled tissue, known as the **calyptrogen** (*calyptra*, cap; *genes*, to form). The calyptrogen is also meristematic, and by repeated divisions of its cells gives rise to the **root-cap.** As the root passes through the hard soil, the root-cap often wears away but then it is renewed by the underlying calyp-

of the bud, which cover and protect the tender growing apex of the stem.

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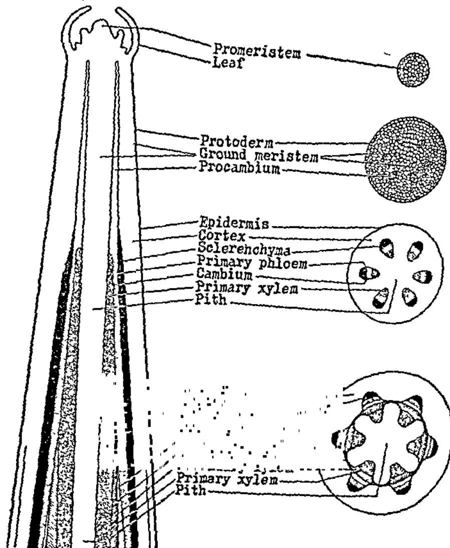


FIG. 420. Stem apex showing primary meristems and differentiation of tissues.

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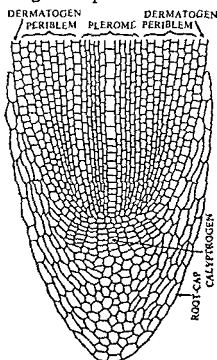


FIG. 421. Root apex.

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trogen. In some plants the dermatogen directly gives rise to the root-cap without the intervention of the calyptrogen. The walls of outer cells of the *root-cap* may be modified into mucilage which helps the root to push *forward in* the soil more easily. The *root-cap* is absent from aquatic plants, although an analogous structure, called *root-pocket*, is *conspicuous* in many of them (*see* p. 23). Sometimes, as in dicotyledons generally, the dermatogen continues upwards as a single outermost layer (epiblema) of the root; but in *monocotyledons* generally the dermatogen is exhausted in the formation of the root-cap so that the outermost layer of the root is derived from the outermost layer of the periblem. At a little distance from the root-tip the outermost layer bears a large number of *unicellular root-hairs*. Root-hairs are mostly absent from aquatic plants.

2. **Periblem.** As in the stem, it is also single-layered at the apex and many-layered higher up. In monocotyledons generally the outermost layer of the periblem forms the outermost layer of the root. Periblem forms the middle region or cortex of the root.

3. **Plerome.** Its structure and function are practically the same as those of the stem. But here some procambial strands give rise to bundles of vessels (xylem) and others to bundles of sieve-tubes (phloem) in an alternating manner.

The above classification of the *apical meristem* into dermatogen, periblem and plerome was introduced in 1870 by Hanstein who considered that the primordial meristem was *sharply separable into* three *distinct regions* or *histogens*. This classification, however, cannot be universally applied, specially in roots and in many stems, where the three regions cannot be recognized.

A new system has, the[illegible] the *primordial meristem* is [illegible] tissues - (1) the **protoderm** [illegible] dermatogen; (2) the procam[illegible] cells in or close to the cent[illegible] a small *group of cells in the ground meristem*, but in *longitudinal section* the procambial cells are seen to be much longer than those of the ground meristem, and many of them pointed at their ends; gradually they become *differentiated into vascular bundles*; and (3) the **ground** or **fundamental meristem** which fills in all the remaining spaces; *these cells are relatively* large, thin-walled and isodiametric, and become differentiated into the hypodermis, primary cortex, endodermis, pericycle, medullary or pith rays and medulla or pith (fig. 420).

CHAPTER III

THE TISSUE SYSTEM

There exists in the higher plant a division of labour, and in response to this, tissues are arranged into three systems, each taking a definite share in the common life-work of the plant. Each system may consist of only one tissue or a combination of tissues which may structurally be of like or different nature, but perform a common function and have the same origin. The three systems are: (I) the **epidermal tissue system**, (II) the **ground or fundamental tissue system**, and (III) the **vascular tissue system.**

I. The Epidermal Tissue System

Epidermis. The epidermal tissue system is derived from the dermatogen of the apical meristem and forms the **epidermis** (*epi*, upon or outer; *derma*, skin) or the outermost skin or covering which extends over the entire surface of the plant body, and is continuous except for certain openings (stomata and lenticels). At surface view the cells of the epidermis are somewhat irregular in outline (see fig. 422) varying in shape and size, but closely fitted together without intercellular spaces. They, however, appear more or less rectangular in cross section. Epidermis is mostly single-layered, but sometimes, as in the leaves of India-rubber plant, banyan, oleander, etc., it becomes few-layered, called *multiple epidermis.* Epidermal cells are parenchymatous in nature with comparatively small amount of cytoplasm lining the cell-wall and a large vacuole filled with colourless cell-sap. In some plants the cells may contain anthocyanins or chromoplasts, but not chloroplasts except in guard cells, ferns, submerged plants and a few others; *in the leaves and young green shoots the epidermis,* however, possesses numerous **stomata** through which an interchange of gases takes place between the plant and the atmosphere. Epidermal cells soon die off and are filled with various substances like tannin, silica particles, gum, mucilage, crystals, etc. Inner and radial walls of epidermal cells are thin, while the outer walls are thick and usually impregnated with cutin or suberin. Cutinization or suberization sometimes extends to the radial walls also. The cutinized layer or the **cuticle** protects the inner cells against loss of water and mechanical injury. Excretion of wax in the form of rods, scales, grains, etc., prevents further loss of water. In many plants epidermal cells often bear outgrowths, known as **hairs** or **trichomes.** These

may be unicellular or multicellular, simple or branched, soft or sharp and stiff. Besides, the epidermis may also bear stinging hairs (see fig. 181), as in nettles, glandular hairs (see fig. 415), as in *Boerhaavia* (B. PUNARNAVA; H. THIKRI), tobacco, *Plumbago* (B. CHITA; H. & P. CHITRAK), etc. A dense coating of hairs, or development of scales, rods, etc., on the epidermal surface is another feature of the epidermis in many plants.

The outermost layer of the root is called the **epiblema or piliferous layer.** It is mainly concerned with the absorption of water and mineral salts from the soil. Thus to increase the absorbing surface which has been estimated to be 5 to 20 times greater the outer walls of most of its cells extend outwards and form tubular unicellular root-hairs. The epiblema is neither cutinized nor is it provided with stomata.

Functions. (1) The primary function of the epidermis is the protection of the internal tissues against mechanical injury, excessive heat or cold, fluctuations of temperature, and attack of parasitic fungi and bacteria; this is due to the presence of cuticle, hairs, tannin, gum, etc. (2) Prevention of excessive evaporation of water from the internal tissues by the development of thick cuticle, wax and other deposition, cutinized hairs, scales, multiple epidermis, etc., is another important function of the epidermis. (3) Protection of the plant against intense illumination (i.e. strong sunlight) and against excessive radiation of heat is mainly afforded by strong cuticle and cutinized hairs, particularly a dense coating of hairs. (4) The epidermis has also to protect the plant against the attack of herbivorous animals; this the epidermis does with the help of sharp and stiff hairs as in some cucurbits, a dense coating of hairs as in *Gnaphalium*, stinging hairs as in nettles (see fig. 181), glandular hairs as in *Boerhaavia* (see 415), silica particles as in many grasses (lemon grass, for example), *Equisetum*, etc., and raphides (see figs. 381-3) as in many aroids. (5) The epidermis also acts as a storehouse of water, as in desert plants. (6) The epidermis sometimes carries on some minor functions such as photosynthesis, secretion, etc.

√**Stomata.** *Structure and Behaviour.* **Stomata** (*stoma*, a mouth) are very minute openings (fig. 422) formed in the epidermal layer in green aerial parts of the plant, particularly the leaves. Roots and non-green parts of the stem are free from them. Each stoma is surrounded by two semi-lunar cells, known as the *guard cells.* The term 'stoma' is often applied to the stomatal opening plus the guard cells. The guard cells are living and always contain chloroplasts, and

their inner walls are thicker and outer walls thinner. They guard the stoma or the passage, i.e. they regulate the opening and closing of it like lips. Sometimes the guard cells are

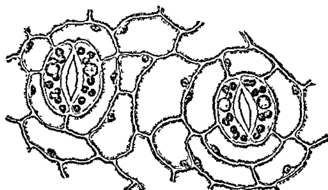


FIG. 422. Stomata (surface view) in epidermal layer.

surrounded by two or more cells which are distinct from the epidermal cells; such cells are called *accessory cells*. In dicotyledonous leaves the stomata remain scattered, while in monocotyledonous leaves they occur in parallel rows. Under normal conditions the stomata remain closed at night, i.e. in the absence of light, and they remain open during the daytime, i.e. in the presence of light. They may close up at daytime when

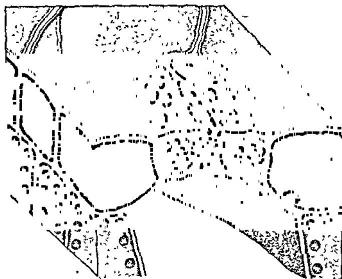


FIG. 423. Diagrammatic representation of a stoma (surface and sectional views).

very active transpiration (evaporation of water) takes place from the surface of the leaf under certain conditions such as dryness of the air, blowing of dry wind and deficient supply

are also the organs through which evaporation of water takes place; in this way the plant gets rid of the surplus water. Stomata are most abundant in the lower epidermis (fig. 424) of the dorsiventral leaf (see p. 77); none (or sometimes very few) are present in the upper (fig. 426). In the isobilateral and centric leaves (see p. 77) stomata are more or less evenly distributed on all sides (see figs. 449-50). In the floating leaves, as in those of the water lily, stomata remain confined to the upper epidermis alone; in the submerged leaves no stoma is present. In desert plants and in those showing xerophytic adaptations, e.g. American aloe or century plant (*Agave*; fig. 427), oleander (*Nerium*; (fig. 428), pine (*Pinus*; see fig. 707), etc., one or more stomata are situated in grooves or pits in the leaf. This is a special adaptation to reduce excessive evaporation, as the stomata sunken in pits are protected from gusts of wind. The number of stomata per unit area varies within wide limits. In ordinary land plants there is an average of about 100 to 300 stomata per square millimetre, sometimes much less or many more. In the floating leaves of aquatic plants stomata may occur to the extent of over 400 per square millimetre, while none in submerged leaves. In desert plants there may be only 10 to 15 stomata per square millimetre; while there are cases with about 1,300 stomata in the same space.

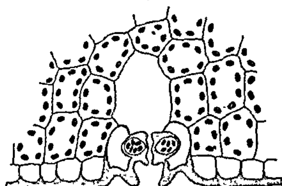


FIG. 427. Sunken stoma in the leaf of American aloe (*Agave*).

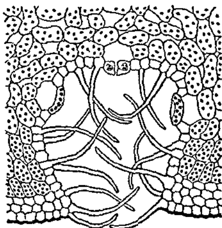


FIG. 428. Sunken stomata in the leaf of oleander (*Nerium*).

II. The Ground or Fundamental Tissue System

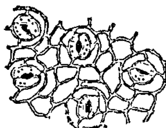
This system forms the main bulk of the body of the plant,

of water in the soil. The intensity of light markedly affects the degree of stomatal opening. The opening and closing of the stomata are due to the movement of the guard cells. When the guard cells become turgid, i.e. full of water, they expand and bulge out in the outward direction, and the stoma is open; when the guard cells become flaccid by losing water the stoma is closed.

The turgidity or flaccidity of the guard cells is due to the presence of sugar or of starch in them. In light the sugar manufactured by the chloroplasts of the guard cells accumulates in them, and being soluble, increases the concentration of the cell sap. Under this condition the guard cells absorb water from the neighbouring cells and become turgid, and the stoma opens. In darkness on the other hand the sugar present in the guard cells becomes converted into starch—an insoluble compound. The concentration of the cell sap is, therefore, lower than that of the neighbouring cells. Under this condition the guard cells lose water and shrink, and the stoma closes. The transformation of sugar into starch at night and vice versa at daytime is due to acidity and alkalinity of the cell-sap of the guard cells. At night photosynthesis being in abeyance carbon dioxide accumulates in the guard cells and the cell-contents become weakly acid. Under this condition sugar becomes converted into starch. During the daytime carbon dioxide is utilized in photosynthesis and thus the cell-contents become slightly alkaline. Under this condition the starch becomes converted into sugar.

There is another hypothesis, called **colloidal hypothesis**, put forward to explain the movement of the guard cells. According to this, the cell-contents become alkaline as a result of the effect of sunlight on guard cells and this causes the colloids present in them to swell, apart from the fact that this causes the transformation of starch into sugar. The swelling of the colloids according to this theory causes the guard cells to burge out and the stoma to open. At night the acidity of the guard cells increases and causes the colloids to shrink again, and thus to close the stoma, apart from the fact that this increased acidity brings about the conversion of sugar into starch.

Functions and Distribution. Stomata are used for interchange of gases between the plant and the atmosphere—oxygen for respiration and carbon dioxide for manufacture of carbo-



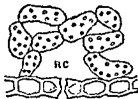




Fig. 424 Fig. 425 Fig. 426

Stomata in betel leaf. Fig. 424. Lower epidermis with numerous stomata (surface view). Fig. 425. Section of leaf (a portion of the lower side); *RC*, respiratory cavity internal to a stoma. Fig. 426. Upper epidermis with no stoma (surface view).

hydrates. For the facility of diffusion of these gases each stoma opens internally into a small cavity, known as the *respiratory cavity* (fig. 425) which in its turn communicates with the system of intercellular spaces and air cavities. Stomata

are also the organs through which evaporation of water takes place; in this way the plant gets rid of the surplus water. Stomata are most abundant in the lower epidermis (fig. 424) of the dorsiventral leaf (see p. 77); none (or sometimes very few) are present in the upper (fig. 426). In the isobilateral and centric leaves (see p. 77) stomata are more or less evenly distributed on all sides (see figs. 449-50). In the floating leaves, as in those of the water lily, stomata remain confined to the upper epidermis alone; in the submerged leaves no stoma is present. In desert plants and in those showing xerophytic adaptations, e.g. American aloe or century plant (*Agave*; fig. 427), oleander (*Nerium*; (fig. 428), pine (*Pinus*; see fig. 707), etc., one or more stomata are situated in grooves or pits in the leaf. This is a special adaptation to reduce excessive evaporation, as the stomata sunken in pits are protected from gusts of wind. The number of stomata per unit area varies within wide limits. In ordinary land plants there is an average of about 100 to 300 stomata per square millimetre, sometimes much less or many more. In the floating leaves of aquatic plants stomata may occur to the extent of over 400 per square millimetre, while none in submerged leaves. In desert plants there may be only 10 to 15 stomata per square millimetre; while there are cases with about 1,300 stomata in the same space.

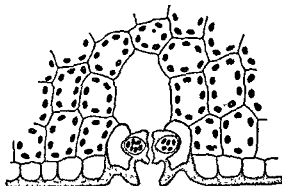


FIG. 427. Sunken stoma in the leaf of American aloe (*Agave*).

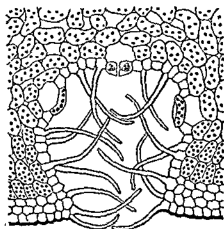


FIG. 428. Sunken stomata in the leaf of oleander (*Nerium*).

II. The Ground or Fundamental Tissue System

This system forms the main bulk of the body of the plant,

and extends from below the epidermis to the centre (excluding the vascular bundles). It is partly derived from the periblem and partly from the plerome. The primary functions that this system carries on are: manufacture of food material and storage of the same; it also serves a mechanical function. This system consists of various kinds of tissues, of which parenchyma is most abundant; other tissues are sclerenchyma and collenchyma, and sometimes also laticiferous tissue and glandular tissue. It is differentiated into the following zones.

1. **Cortex.** *It is situated internal to the epidermis and is* limited internally by the endodermis. Its thickness varies from a few to many layers. The cells of the cortex are essentially parenchymatous, but it may contain collenchyma, sclerenchyma, stone cells and many kinds of secretory and storage structures. In dicotyledonous stems (see fig. 437) the cortex is usually differentiated into (*a*) a few layers of collenchyma or sclerenchyma forming the **hypodermis,** (*b*) a few layers of green or colourless, closely or loosely arranged, thin-walled cells—the parenchyma of the **cortex,** and (*c*) a single wavy layer of **endodermis or starch sheath** which is not often conspicuous. In monocotyledonous stems (see fig. 441), owing to scattered arrangement of vascular bundles, the cortex is not marked out into the cortex proper and the endodermis; sclerenchyma is, however, often present as hypodermis. In roots (see fig. 444) the cortex consists of (*a*) many layers of thin-walled parenchymatous cells with intercellular spaces, and (*b*) a distinct, circular layer of endodermis.

Functions. In stems the cortex primarily functions as a protective tissue; its secondary functions are storage, photosynthesis, etc. In roots the cortex is essentially a storage tissue. It also acts as a pumping station, whose individual cells act as *pumps forcing water,* absorbed by the root-hairs, into the xylem vessels.

Endodermis is the inner limiting layer of the cortex and is formed of vertically elongated cells; in cross section the endodermis appears as a single layer of barrel-shaped cells without intercellular spaces. The layer is wavy in stems and often not readily distinguishable or even altogether wanting; while in roots it is circular and well-defined. The cells are living containing abundant protoplasm, large nuclei and often starch grains—*hence this layer is also called* **starch sheath.** Some cells of the endodermis may contain mucilage, tannin, gum, etc. The outer walls of endodermal cells are thin, while radial and inner walls are often thickened, being cutinized or

suberized and also sometimes lignified, particularly in roots. The thickened walls are provided with numerous, simple pits. Sometimes the thickening takes the form of a band or strip surrounding each cell ; this band is called the **Casparian strip.** Among the thick-walled cells of the endodermis, as in many roots, often occur, opposite to protoxylem elements, some small thin-walled cells ; these are called **passage cells** (see fig. 71). Through them the sap absorbed by root-hairs enters the xylem vessels. Endodermis is well developed in the roots of all plants, in the stems of pteridophytes and herbaceous plants, in the rhizome, and in the leaves of gymnosperms ; it is, however, absent or indistinct in the stems of woody plants and in the leaves of angiosperms.

Functions. Functions of the endodermis are somewhat obscure. Some regard it as a water-tight jacket between the xylem and the surrounding tissues. It may act as an air-dam preventing diffusion of air into the vessels and thus clogging them. It may be a 'diffusion layer' preventing loss of water, mineral salts and food from the vascular bundles. It may be a storage tissue containing starch grains, as in dicotyledons. It may be connected with the osmotic pressure that develops in the root-cortex. It may serve as a passage of water from the cortex of the root to the protoxylem.

2. **Pericycle.** It forms a multi-layered zone between the endodermis and the vascular bundles and occurs as a cylinder encircling the vascular bundles and the pith, as in dicotyledonous stems. It may consist wholly of sclerenchyma forming a continuous zone, as in gourd (*Cucurbita*) stem but more commonly it is made of both parenchyma and sclerenchyma, the latter forming isolated strands in it (the pericycle). Each such strand associated with the phloem or bast of the vascular bundle in the form of a cap is known as the **hard bast,** as in sunflower stem. Many of the textile fibres of commerce are obtained from the pericycle. In rare cases the pericycle is collenchymatous or is altogether wanting. In the roots and stems of some aquatic plants the pericycle is absent, and it is not distinguishable in the monocotyledonous stems. In roots the pericycle consists of a single layer of small, very thin-walled, more or less barrel-shaped cells.

Functions. In all roots the pericycle is the seat of origin of lateral roots. In dicotyledonous roots it further gives rise to secondary meristems—a portion of the cambium and later the whole of the cork-cambium. In all stems the pericycle is the

seat of origin of adventitious roots. Otherwise its functions are mechanical, storage, secretion, etc.

3. **Pith and Pith Rays.** The **pith** or **medulla** forms the central core of the stem and the root and is usually made of large-celled parenchyma with abundant intercellular spaces. In the dicotyledonous stem the pith is often large and well developed, while in the monocotyledonous stem, owing to scattered distribution of vascular bundles, it is not distinguishable; in the dicotyledonous root the pith is either small or absent, bigger vessels having met in the centre; while in the monocotyledonous root a distinct pith is present. It is often parenchymatous, but sometimes sclerenchymatous. In the dicotyledonous stem the pith extends outwards to the pericycle between the vascular bundles. Each extension which is a strip of parenchyma is called the **pith ray** or **medullary ray.** It is not present as such in the root. The cells of the pith and the pith ray are usually larger than those of the cortex and enclose numerous intercellular spaces.

Functions. They serve to store food material. The function of the sclerenchymatous pith is, of course, mechanical. The medullary rays further transmit water and food material outwards to the peripheral tissues, and is the seat of origin of a strip of cambium (i.e. the interfascicular cambium; see fig. 453B).

III. The Vascular Tissue System

This system consists of a number of vascular bundles which are distributed in the **stele.** The stele is the central cylinder *of the stem and the root (and the pine leaf)* surrounded by the endodermis and consists of vascular bundles, pericycle, pith and medullary rays. Each bundle is made up of **xylem tissue** and **phloem tissue** with or without a cambium, as in stems, or of only one kind of tissue—xylem or phloem, as in roots. *The function of this system is to conduct water and raw food materials from the roots to the leaves, and prepared food materials from the leaves to the storage organs and the growing regions.* The elements of a vascular bundle are derived from the *procambial strands* of the plerome, which show a tendency to elongate even at an early stage. The vascular bundles may be regularly arranged in a ring, as in the stems of dicotyledons, gymnosperms and in all roots, or they may be scattered in the ground tissue, as in the stems of monocotyledons.

Elements of a Vascular Bundle (fig. 429). A vascular bundle of a dicotyledonous stem, when fully formed, *consists of three* well-defined tissues: (1) xylem or wood, (2) phloem *or bast,*

and (3) cambium. They have different kinds of tissue-elements.

1. **Xylem or Wood** (see pp. 217-9). It lies towards the centre, and is composed of the following elements: (1) tracheae or vessels, (2) some tracheids, (3) a number of wood fibres, and (4) a small patch of wood parenchyma. Vessels are of various kinds (see pp. 218-9) such as *spiral, annular, scalariform, reticulate* and *pitted* (with simple or bordered pits). Some tracheids also lie associated with the vessels. Wood fibres and wood parenchyma are ordinary sclerenchymatous and parenchymatous cells lying associated with the wood or xylem. These are provided with simple pits in their walls. Sometimes in the secondary wood the xylem parenchyma becomes thick-walled

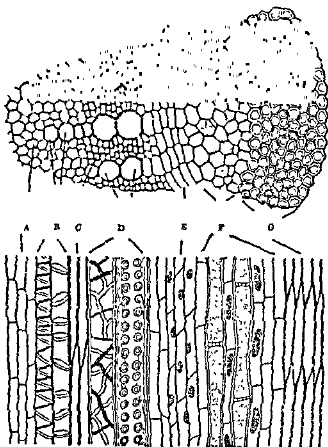


FIG. 429. Vascular bundles of sunflower stem in transverse and longitudinal sections. *A*, wood parenchyma; *B*, protoxylem (annular and spiral vessels); *C*, tracheids and wood fibres; *D*, metaxylem (reticulate and pitted vessels); *E*, cambium; *F*, phloem (sieve-tubes, companion cells and phloem parenchyma); and *G*, sclerenchyma (hard bast).

and lignified. Xylem vessels and tracheids are used for the conduction of water and mineral salts from the roots to the leaves and other parts of the plant ; xylem parenchyma assists them in their task and also serves for food storage, and wood fibres give proper rigidity to the xylem. Except the wood parenchyma all the other elements of xylem are dead and lignified, and hence their secondary function is to give mechanical strength to the plant.

The first-formed xylem or **protoxylem** consists of *annular, spiral* and *scalariform* vessels ; it lies towards the centre of the stem and its vessels have smaller cavities. The later-formed xylem or **metaxylem** consists of *reticulate* and *pitted* vessels and some *tracheids* ; it lies away from the centre and its elements have much bigger cavities. Of course all transitional stages are noticed between protoxylem and metaxylem. The development of xylem is *centrifugal* in the stem, or, in other words, it is said to be *endarch* (meaning inner origin).

2. **Phloem or Bast** (see pp. 219-21). It lies towards the circumference, and consists of (1) sieve-tubes, (2) companion cells, and (3) phloem parenchyma. Companion cells and phloem parenchyma are provided with simple pits, particularly in the walls lying against the sieve-tubes. Phloem as a whole is used for translocation of prepared food materials from the leaves to the storage organs and also to the different growing regions. Sieve-tubes carry proteins and many carbohydrates, phloem parenchyma conducts amines and amino-acids and soluble carbohydrates, and companion cells transmit many of the soluble food materials sideways to the surrounding tissues. *All the elements of phloem are made of cellulose, and are living.* Primary phloem hardly contains bast fibres but it may be capped by a patch of sclerenchyma, called *hard bast*, as seen in the sunflower stem (see fig. 437).

The outer portion of phloem *consisting of narrow* sieve-tubes constitutes the **protophloem**, and the inner portion consisting of bigger sieve-tubes constitutes the **metaphloem**.

3. **Cambium.** It is a thin strip of primary meristem lying in between xylem and phloem. *It consists of one or* a few layers of thin-walled and roughly retangular cells. Although cambial cells look rectangular in transverse section, they are much elongated with often oblique ends. They become flattened tangentially, i.e. at right angles to the radius of the stem.

Note. The wood of gymnosperms and ferns consists exclusively of tracheids ; no vessels are present there. The primary wood consists of annular and spiral tracheids, and the secondary wood (in gymnosperms) consists of

pitted tracheids (with bordered pits.) Also no companion cells are formed in
here is seldom any
from them; in roots

Types of Vascular Bundles. According to the arrangement of xylem and phloem, the vascular bundles are of the following types:

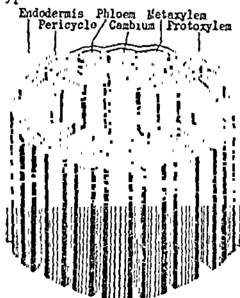


Fig. 430

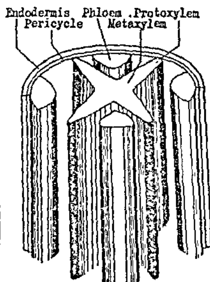


Fig. 431

Vascular System (diagrammatic). Fig. 430 Stele of a dicotyledonous stem. Fig. 431. Stele of a dicotyledonous root.

1. **Radial,** when xylem and phloem form separate bundles and these lie on different radii alternating with each other, as in roots (figs. 431-2). These are the most primitive types of bundles.

2. **Conjoint,** when xylem and phloem combine into one bundle. There are different types of conjoint bundles.

(*a*) **Collateral,** when xylem and phloem lie together on the same radius, xylem being internal and phloem external. When in a collateral bundle the cambium is present, as in all dicotyledonous stems, the bundle is said to be *open* (fig. 433A), and when the cambium is absent it is said to be *closed* (fig. 433B), as in monocotyledonous stems.

(*b*) **Bicollateral** (fig. 434), when in a collateral bundle both phloem and cambium occur twice—once on the outer side of xylem and then again on the inner side of it. The sequence is outer phloem, outer cambium, xylem, inner cambium and inner phloem. Bicollateral bundle is characteristic of gourd family or *Cucurbitaceae*; it is also found sometimes in potato family or *Solanaceae*. A bicollateral bundle is always open.

(c) **Concentric,** when xylem lies in the centre and is surrounded by phloem (fig. 435A), as in ferns, *Selaginella* and some water plants, or phloem lies in the centre and is surrounded by xylem (fig. 435B); the latter is an advanced type

Fig. 432

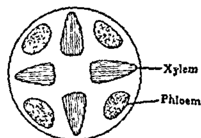
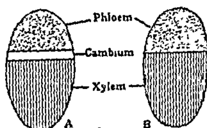
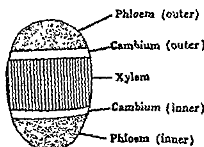


Fig. 433





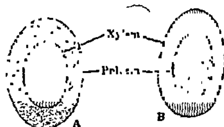
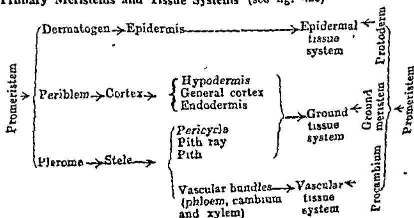


Fig. 434 Fig. 435

Types of Vascular Bundles. Fig. 432. Radial Fig. 433. Collateral—*A*, open; *B*, closed. Fig. 434. Bicollateral Fig. 435. Concentric—*A*, xylem central; *B*, phloem central.

found only in some monocotyledons, e.g. sweet flag (*Acorus*; B. & H. BOCH), dragon plant (*Dracaena*) and dagger plant (*Yucca*). A concentric bundle is always closed.

Primary Meristems and Tissue Systems (see fig. 420)



[illegible] [repre]sented by semi-
[illegible] [thick]ening masses of
[illegible] [wit]h the phloem of
[illegible] [roo]t. The middle
[illegible] [fair]ly big polygonal
[illegible] [betwe]en two vascular
[illegible] [sun]flower stem, and
[illegible] from below the
[illegible] [comp]osed of round or
[illegible] [numer]ous intercellular
[illegible] [collate]ral and open, and
[illegible] [comp]osed of (1) phloem
[illegible] composed only of
[illegible] [consis]ts of (a) sieve-tubes
[illegible] [tha]n the rest of the
[illegible] [t]he sunflower stem
[illegible] [siev]e-tube may be seen
[illegible]. The rest of the
[illegible] [paren]chyma, known as
[illegible] [e]lements are living.
[illegible] [compose]d of thin-walled
[illegible] [arrang]ed in radial rows
[illegible] [s]mall in size and
[illegible] [c]omparatively old
[illegible] continuous from
[illegible] [div]ision of its cells
[illegible] [mark]s the beginning
[illegible] large
[illegible] [re]cognize
[illegible] [o]r vessels
[illegible] and

CHAPTER IV

INTERNAL STRUCTURE OF STEMS

DICOTYLEDONOUS STEMS

1. Young Sunflower Stem (figs. 436-7)

Prepare a thin transverse section of [illegible] stain it with safranin. At first note under a [illegible]

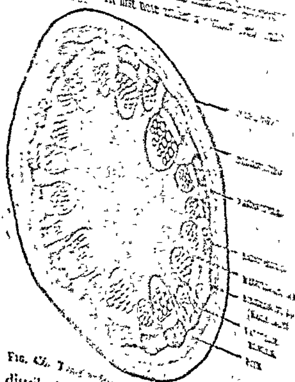


FIG. 436. [illegible]

distribution of [illegible] and the arrangement of vascular bundles [illegible] pocket lens. Then under a microscope study [illegible] from the periphery to the centre (fig. 437).

1. *Epidermis.* It forms the outermost layer, and consists of a single row of cells flattened tangentially and fitting closely along their [illegible] with a well-defined cuticle extending over it. Here and there it bears some multicellular hairs and a few stomata [illegible] the guard cells of the stomata [illegible]

2. *Cortex.* [illegible] external collenchyma [illegible] sheath or endodermis [illegible] below the epidermis [illegible] Collenchyma [illegible] against the [illegible]

deposit of cellulose impregnated *with pectin*. *The cells* are living and contain a number of chloroplasts. (*b*) **Parenchyma** of the cortex—in the central region the cortex consists of a

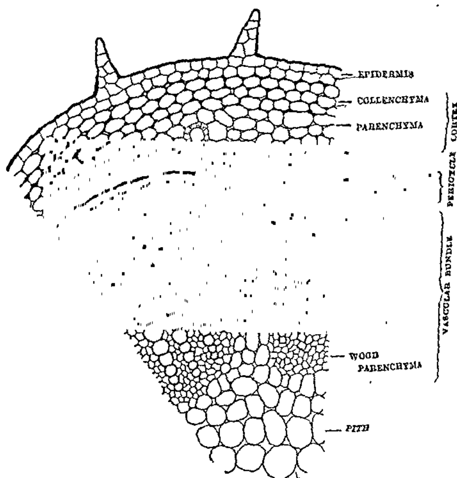


FIG. 437. Young sunflower stem (a sector) in transection, as seen under a microscope.

few layers of thin-walled, large, rounded or oval, parenchymatous cells. It may be reduced to 1 or 2 layers outside the vascular bundle. There are conspicuous intercellular spaces in it. Some isolated resin ducts, each surrounded by a layer of small thin-walled living cells, are also to be seen here and there in it. (*c*) **Endodermis**—it is the innermost layer of the cortex and demarcates it from the stele. The cells are more or less barrel-shaped and fit closely without intercellular spaces. *Endodermis is conspicuous* outside the patch of sclerenchyma, but loses its identity on either side. It almost invariably contains starch grains and is also known as the *starch sheath*.

3. **Pericycle.** It is the region lying in between the endo-

dermis and the vascular bundles, and is represented by semilunar patches of sclerenchyma and the intervening masses of parenchyma. Each patch lying associated with the phloem of the vascular bundle is called the **hard bast.** The middle lamella is very prominent in this tissue.

4. **Medullary Rays.** A few layers of fairly big polygonal or radially elongated cells, lying in between two vascular bundles, constitute the medullary rays.

5. **Pith.** It is very elaborate in the sunflower stem, and occupies the major portion of it. It extends from below the vascular bundles to the centre, and is composed of round or polygonal, thin-walled cells with conspicuous intercellular spaces.

6. **Vascular Bundles.** These are collateral and open, and are arranged in a ring. Each bundle is composed of (1) **phloem** or **bast,** (2) **cambium** and (3) **xylem** or **wood.**

(1) **Phloem.** It lies externally and is composed only of thin and cellulose-walled elements. It consists of (*a*) **sieve-tubes** which appear as slightly larger cavities than the rest of the phloem. On the whole the sieve-tubes of the sunflower stem are very narrow. Associated with each sieve-tube may be seen a smaller cell; this is (*b*) the **companion cell.** The rest of the phloem is packed with small-celled parenchyma, known as (*c*) the **phloem parenchyma.** All the phloem elements are living, and contain various kinds of food material.

(2) **Cambium.** Passing inwards, a band of thin-walled tissue is seen, whose cells are regularly arranged in radial rows and are roughly rectangular in shape, very small in size and thin-walled. (If the section be cut through comparatively old portion of the stem the cambium is seen to be continuous from one vascular bundle to another, and the division of its cells noted both inside and outside. This indicates the beginning of secondary growth.)

(3) **Xylem or Wood.** It lies internally and consists of the following elements: (*a*) **Wood Vessels.** Some large cavities, arranged in a few radial rows, can be easily recognized in the wood; these are the wood vessels. The smaller vessels constituting the *protoxylem* lie towards the centre, and the bigger ones constituting the *metaxylem* lie away from the centre. Protoxylem consists of annular, spiral and scalariform vessels, and metaxylem of reticulate and pitted vessels. Their walls are always thick and lignified. (*b*) **Tracheids.** Surrounding the metaxylem vessels and lying in between them some small, thick-walled cells can be seen; these are the tracheids. In transverse section of the stem they are hardly distinguished from the wood

fibres which lie mixed up with them. (*c*) **Wood Fibres.** These appear somewhat irregular and polygonal in section. They are thick-walled and lignified, and stained like the wood vessels. Excepting the vessels nearly the whole of the wood is packed with these elements. (*d*) **Wood Parenchyma.** A patch of parenchymatous cells is to be seen on the inner side of the bundle surrounding the protoxylem; this is the wood parenchyma. The cells of the wood parenchyma retain their protoplasm.

II. Young Cockle-bur (*Xanthium*) **Stem** (fig. 438).

In a thin transverse section stained properly with safranin note the following tissues from the circumference to the centre.

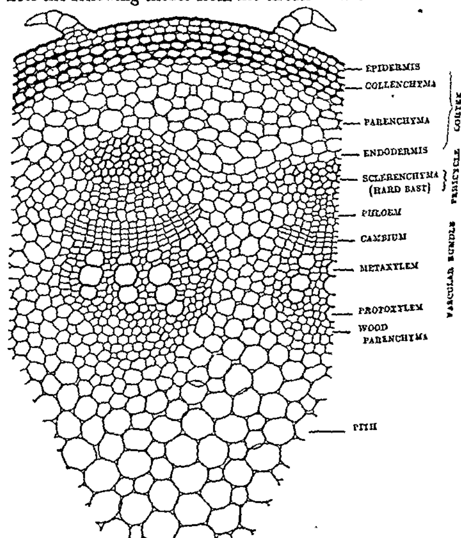


FIG. 438. Young cockle-bur (*Xanthium*) stem (a sector) in transection, as seen under a microscope.

1. **Epidermis.** It is the single outermost layer having cuticle, some *multicellular hairs and a few stomata.*

2. **Cortex.** It consists externally of a few layers of (*a*) **collenchyma**, a few layers of large thin-walled (*b*) **parenchyma**, and internally a wavy layer of (*c*) **endodermis** or starch sheath.

3. **Pericycle.** It lies in between the endodermis and the vascular bundles, and consists of some patches of sclerenchyma (hard bast) associated with the vascular bundles, and the intervening bands of parenchyma.

4. **Medullary Rays.** Each ray consists of a mass of parenchyma lying in between two vascular bundles.

5. **Pith.** *It is large and well developed occupying the* whole of the central part of the stem. It consists of a mass of large, thin-walled, parenchymatous cells, leaving a lot of intercellular spaces in between them.

6. **Vascular Bundles.** These are collateral and open, and are arranged in a ring. Each bundle consists of (*a*) **phloem** lying externally, (*b*) **cambium** *lying in the middle made of a* few layers of small thin-walled roughly rectangular cells (as seen in a transection), and (*c*) **xylem** lying internally with *protoxylem* towards the centre and *metaxylem* towards the periphery. Elements of the vascular bundle are the same as those of the sunflower stem.

***III.* Young** (*Cucurbita*) **Stem** (figs. 439-40)

Prepare a thin transverse section of the stem and properly stain it with safranin. Note under a pocket lens that it is hollow, and has usually five ridges and five furrows, and that the vascular bundles are usually ten in number and arranged in two rows, those of the outer row corresponding to the ridges and those of the inner to the furrows (fig. 439). Then under a microscope note the following tissues from the periphery to the central cavity (fig. 440).

1. **Epidermis.** It is the single outermost layer passing over the ridges and furrows; it often bears many long and narrow multicellular hairs.

2. **Cortex.** It consists of external collenchyma, central parenchyma and internal endodermis. (*a*) **Collenchyma** lies immediately below the epidermis, and consists of six or seven (sometimes more) layers of cells in the ridges, and in the furrows the number of layers is reduced to two or three, sometimes none; in the furrows collenchyma is interrupted by the underlying *parenchyma which is seen to pass right up*

to the epidermis. Collenchyma contains many chloroplasts. (b) **Parenchyma** of the cortex forms a narrow zone, two or three layers thick; here and there it passes outwards right up to the

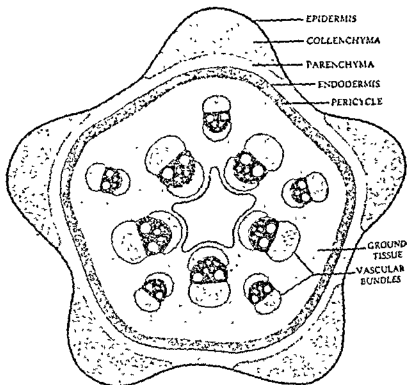


FIG. 439. Young *Cucurbita* stem in transection, as seen under a pocket lens

epidermis through the collenchyma. Chloroplasts are abundant in the cortex. (c) **Endodermis** is the innermost layer of the cortex, lying immediately outside the sclerenchyma. This layer is wavy in outline and contains starch grains.

3. **Pericycle.** Below the endodermis there is a zone of sclerenchyma which represents the pericycle. This zone consists of four or five layers of thick-walled, lignified cells which are polygonal in shape.

4. **Ground Tissue.** A continuous mass of thin-walled cells of the ground tissue extends from below the sclerenchyma to the pith cavity; in this tissue lie embedded the vascular bundles.

5. **Vascular Bundles.** These are *bicollateral*, usually ten in number, and are arranged in two rows. Each bundle consists of (1) **xylem,** (2) **two strips of cambium,** and (3) **two patches of phloem.**

(1) **Xylem** occupies the centre of the bundle, and consists, on the outer side, of very wide vessels (pitted) which constitute

the *metaxylem*, and on the inner side, of narrower vessels which constitute the *protoxylem*. There are some tracheids, wood fibres and wood parenchyma also in the xylem. Vessels are not regularly arranged in radial rows, as in the sunflower stem.

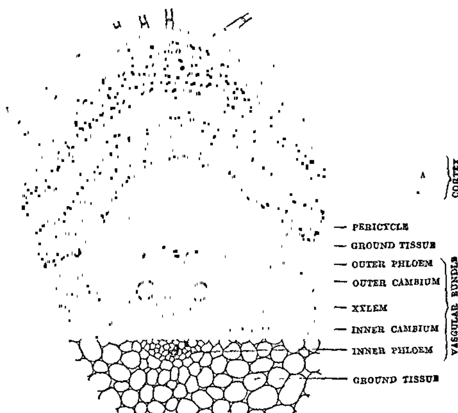


FIG. 440. Young *Cucurbita* stem (a sector) in transection, as seen under a microscope.

(2) **Cambium.** This tissue is seen on either side of the xylem, forming a narrow strip between phloem and xylem to the inside, and between xylem and phloem to the outside; its cells are thin-walled and rectangular, and arranged in radial rows. The outer cambium is many-layered and is more or less flat, and the inner cambium is few-layered and curved. Each strip of cambium gradually merges into phloem and xylem.

(3) **Phloem** occurs in two patches—the outer and the inner. Note that the outer phloem is plano-convex and the inner one semi-lunar in shape. Each patch of phloem consists of sieve-tubes, companion cells, and phloem parenchyma. Sieve-tubes are very conspicuous in the phloem of the *Cucurbita* stem.

Here and there sieve-plates with perforations in them may be distinctly seen. The rest of the phloem is made up of small, thin-walled cells which constitute the phloem parenchyma.

MONOCOTYLEDONOUS STEMS

1. Indian Corn or Maize Stem (fig. 441)

Cut a thin transverse section and properly stain it with safranin. Note under the microscope the following tissues from the circumference to the centre.

1. **Epidermis.** A single outermost layer with a thick cuticle on the outer surface. Here and there in the epidermis a few stomata may be seen.

2. **Sclerenchyma.** It forms a narrow zone of hypodermis, usually two or three layers thick, lying below the epidermis.

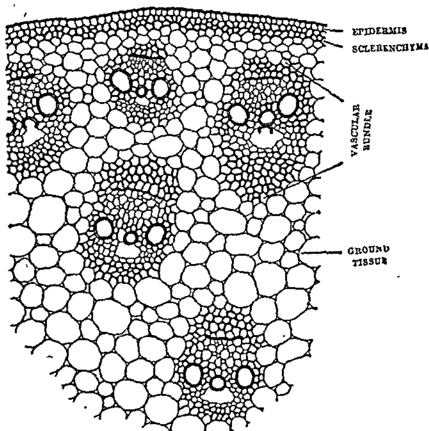


FIG. 441. Maize or Indian corn stem (a sector) in transection, as seen under a microscope.

3. **Ground Tissue.** It is the continuous mass of thin-walled parenchymatous cells, extending from below the scleren-

chyma to the centre. It is not differentiated into cortex, endodermis, pericycle, etc., as in a dicotyledonous stem. The cells of the ground tissue enclose numerous intercellular spaces among them.

4. **Vascular Bundles** (fig. 442). These are collateral and closed, and lie scattered in the ground tissue; they are more numerous, and lie closer together nearer the periphery than the centre. The peripheral ones are also seen to be smaller in size than the central ones. Each vascular bundle is somewhat oval in general outline and is more or less completely surrounded by a **sheath** of sclerenchyma which is specially developed on the two sides—upper and lower. It consists of two parts, viz. xylem and phloem.

(1) **Xylem** mainly consists of usually four distinct vessels arranged in the form of a Y, and a small number of tracheids arranged irregularly. The two smaller vessels (annular and spiral) lying radially towards the centre constitute the *protoxylem*, and the two bigger vessels (pitted) lying laterally

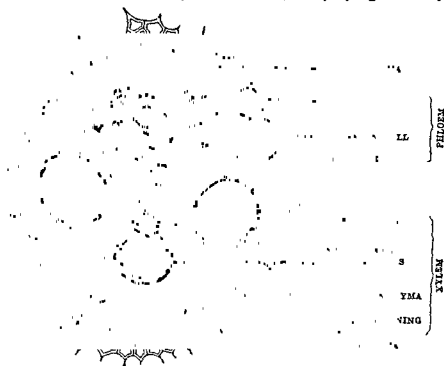


FIG. 442. A vascular bundle of maize stem (magnified).

together with the small pitted tracheids lying in between them constitute the *metaxylem*. Besides, thin-walled wood (or xylem) parenchyma almost surrounding a conspicuous water-

containing cavity is present in the protoxylem, and a few wood fibres occur associated with the tracheids in between the two big pitted vessels. The said water-containing cavity has been formed lysigenously, i.e. by the breaking down of the inner protoxylem vessel and the contiguous parenchyma during the rapid growth of the stem.

(2) **Phloem** consists exclusively of sieve-tubes and companion cells; no phloem parenchyma is present in the monocotyledonous stem. The outermost portion of the phloem, which is a broken mass, is the *protophloem*, and the inner portion is the *metaphloem*. The former soon gets disorganized, and the latter shows distinct sieve-tubes and companion cells.

Differences between Dicotyledonous and Monocotyledonous Stems

	Dicotyledonous stem (e.g. sunflower)	Monocotyledonous stem (e.g. maize)
1. Hypodermis	... collenchymatous ...	sclerenchymatous
2. Cortex	... a few layers of parenchyma	a continuous mass of parenchyma up to the centre (ground tissue) without differentiation into distinct tissues
3. Endodermis	... a wavy layer	
4. Pericycle	... a zone of parenchyma and sclerenchyma	
5. Medullary Ray	... a strip of parenchyma in between vascular bundles	
6. Pith	.. the central cylinder ...	not marked out
7. Vascular Bundles	(a) collateral and open...	collateral and closed
	(b) arranged in a ring...	scattered
	(c) of uniform size ...	larger towards the centre
	(d) phloem parenchyma present ...	it is absent
	(e) usually wedge-shaped	usually oval
	(f) bundle sheath absent	strongly developed

II. Flowering Stem (Scape) of *Canna* (fig. 443)

A thin transverse section shows the following structure:

1. **Epidermis.** It is the outermost layer consisting of a single row of very small, polygonal cells flattened tangentially.

2. **Ground Tissue System.** From below the epidermis to the centre the whole mass of tissues, leaving out the vascular bundles, constitutes the ground tissue system. It is differentiated into (a) **cortex** consisting of two layers of fairly large polygonal cells, (b) **chlorophyllous tissue** consisting of one or two layers of chloroplast-bearing cells, intruding inwards here and there, (c) several patches of *sclerenchyma* of different sizes lying against the chlorophyllous tissue, and (d) **ground tissue** consisting of a continuous mass of large, thin-walled, parenchy-

matous cells, containing starch grains and enclosing numerous intercellular spaces between them.

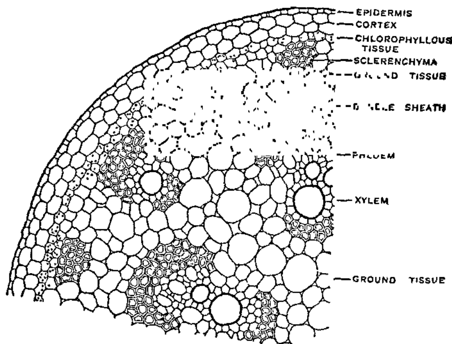


FIG. 443. Flowering stem (scape) of *Canna* (a sector) in transection, as seen under a microscope.

3. **Vascular Bundles.** These are numerous and are of different sizes, lying scattered in the ground tissue. Each bundle is closed and collateral. It is incompletely surrounded by a sheath of sclerenchyma **(bundle sheath)**, with a distinct patch of it on the outer side in the form of a cap, and a thin strip on the inner side ; seldom a regular and complete sheath is formed encircling the vascular bundle. Each bundle consists of (*a*) xylem on the inner side, and (*b*) phloem on the outer. **Xylem** consists of a large prominent spiral vessel, with often one or two smaller ones, also spiral in nature, lying usually on its outer side, and some parenchyma. **Phloem** consists of sieve-tubes and companion cells.

CHAPTER V

INTERNAL STRUCTURE OF ROOTS

I. Young Dicotyledonous Root (fig. 444)

A thin transverse section through a young dicotyledonous root shows the following arrangement of tissues from the circumference to the centre.

1. **Epiblema or Piliferous Layer.** It is a single outermost layer of thin-walled cells; outer walls of most of these cells extend outwards and form unicellular root-hairs. This layer is used for absorption of water and various solutes from the soil and, therefore, it has no cuticle. Root-hairs increase the absorbing surface of the root.

2. **Cortex.** It consists of many layers of thin-walled rounded cells, with numerous intercellular spaces among them. The cells of the cortex contain leucoplasts and store starch grains. The epiblema is, in some cases, only short-lived; as it dies off, a few outer layers of the cortex become cutinized and form the *exodermis* of the root.

3. **Endodermis.** This is a single circular layer of barrel-shaped cells which are closely packed without intercellular spaces. The radial walls of this layer are often thickened, and

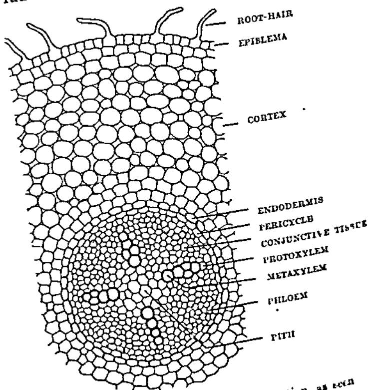


FIG. 444. Young dicotyledonous root in transaction, as seen under a microscope.

sometimes this thickening extends to the inner walls also, and not infrequently the walls abutting upon the protoxylem are provided with simple pits. Endodermis is the innermost layer

of the cortex and occurs as a ring (or cylinder) around the stele. Here and there, particularly lying against the protoxylem, small thin-walled cells are often found in the endodermis; these are the *passage cells*.

4. **Pericycle.** It lies internal to the endodermis, and is single-layered like the latter; its cells are very thin-walled. and contain abundant protoplasm.

5. **Conjunctive Tissue.** The parenchyma lying in between and around the bundles constitutes the *conjunctive tissue*.

6. **Pith.** This occupies only a small area in the centre of the root. Sometimes the pith is nearly obliterated owing to the wood vessels meeting in the centre.

7. **Vascular Bundles.** These are arranged in a ring, as in the dicotyledonous stem, but here xylem and phloem form an equal number of separate bundles, and their arrangement is *radial* (see p. 239). *Protoxylem lies away from the centre so that the development of wood is centripetal*, or, in other words, xylem is said to be *exarch*. The number of xylem or phloem bundles varies from two to six (di-, tri-, tetra-, penta or hexarch), less frequently more. The cambium makes its appearance only later as a secondary meristem. **Phloem bundle** consists of sieve-tubes, companion cells and phloem parenchyma. **Xylem bundle** consists of *protoxylem* which lies towards the circumference abutting on the pericycle, and *metaxylem* towards the centre. Protoxylem is composed of small vessels (annular and spiral) and metaxylem of bigger vessels (reticulate and pitted). The metaxylem groups often meet in the centre, and then the pith is obliterated (it gets disorganized).

II. Monocotyledonous Root (fig. 445)

A thin transverse section through a monocotyledonous root reveals the following tissues under the microscope.

1. **Epiblema or Piliferous Layer.** This is the single outermost layer with a number of unicellular root-hairs.

2. **Cortex.** This is a many-layered zone of rounded or oval cells with intercellular spaces among them. As the epiblema dies off a few outer layers of the cortex become cutinized and form the *exodermis*.

3. **Endodermis.** This is the innermost layer of the cortex and forms a definite ring around the stele. Radial walls and often the inner walls of the endodermis are considerably thickened. Cells of the endodermis are barrel-shaped. *Passage cells* are often present in this layer, lying against the protoxylem.

4. **Pericycle.** It is the ring-like layer lying internal to the endodermis.

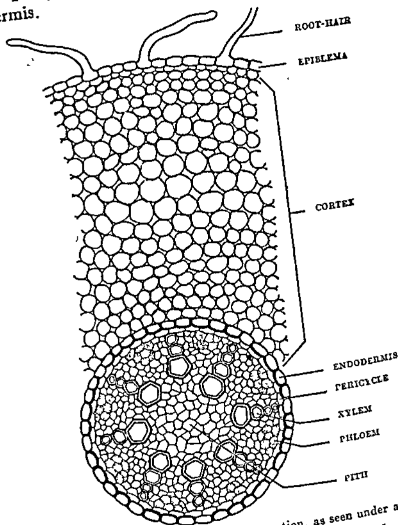


FIG. 445. Monocotyledonous root in transection, as seen under a microscope.

5. **Conjunctive Tissue.** The parenchyma in between and around the vascular bundles is known as the *conjunctive tissue.*

6. **Pith.** The parenchymatous mass of cells in the central portion of the root is the pith. It is well developed in most monocotyledonous roots. In some cases the pith becomes thick-walled and lignified.

7. **Vascular Bundles.** Xylem and phloem form an equal number of separate bundles, and they are arranged in a ring. The arrangement is *radial* (see p. 239). Bundles are numerous (polyarch). It is only in exceptional cases that they are limited in number. The development of wood is *centripetal.* Phloem bundle consists of sieve-tubes, companion cells and

phloem parenchyma. **Xylem bundle** consists of *protoxylem* which lies abutting on the pericycle, and *metaxylem* towards the centre, i.e. xylem is exarch. Protoxylem consists of annular and spiral vessels, and metaxylem of reticulate and pitted vessels. A few isolated, big vessels may often be seen in the pith.

Differences between Dicotyledonous and Monocotyledonous Roots

	Dicotyledonous root	Monocotyledonous root
1. Xylem bundles	vary from 2 to 6 (di- to hexarch), rarely more	numerous (polyarch), rarely a limited number, as in onion
2. Pith ...	small or absent ..	large and well developed
3. Pericycle ...	gives rise to lateral roots and secondary meristems, i.e. cambium and cork-cambium	gives rise to lateral roots only
4 Cambium ..	appears later as a secondary meristem	altogether absent

Differences between Dicotyledonous Stem and Dicotyledonous Root

	Dicotyledonous stem	Dicotyledonous root
1. Epidermis .	with multicellular hairs and cuticle, and often with stomata	epiblema with numerous unicellular hairs, but no stoma or cuticle
2 Hypodermis ..	collenchymatous or sclerenchymatous	always absent
3 Cortex ...	a few layers, often with chloroplasts	many layers, often with leucoplasts
4. Endodermis .	a wavy layer, often not very conspicuous	a ring-like, distinct layer, often with radial and inner walls thickened
5 Pericycle ...	a few layers, often with sclerenchyma	a thin ring-like layer
6. Vascular bundles	many, collateral and open, with centrifugal xylem	2 - to 6, radial, with centripetal xylem
7. Pith ...	large	small or absent

Differences between Monocotyledonous Stem and Monocotyledonous Root

	Monocotyledonous stem (e g. maize stem)	Monocotyledonous root (e.g. *Crinum* root)
1. Epidermis ...	with thick cuticle and often with stomata	epiblema with no cuticle or stoma, but with numerous unicellular hairs
2. Hypodermis ..	sclerenchymatous ...	always absent
3. Cortex ...	not differentiated but a continuous mass of parenchyma forming the ground tissue	many layers of thin walled parenchyma
4. Endodermis ...	not marked out ...	a definite ring like layer, often with radial and inner walls thickened
5. Pericycle ...	not marked out ...	a thin ring-like layer
6. Conjunctive tissue	not marked out ...	the parenchyma in between xylem and phloem bundles

	Monocotyledonous stem (e.g. maize stem)	Monocotyledonous root (e.g. *Crinum* root)
7. Pith ...	not marked out ...	big, well developed and parenchymatous
8. Vascular bundles	very many, collateral and closed, with centrifugal xylem, scattered in the ground tissue	many, radial, with centripetal xylem, arranged in a ring

Transition from the Root to the Stem (fig. 446). Vascular bundles are continuous from the root to the stem, but we find different arrangements in the two cases. In the stem they are collateral, but in the root they are radial. How and where has this transition taken place? If we trace the vascular bundles from the root to the stem we find that each xylem and phloem bundle divides radially into two. Phloem bundles remain practically in the same position, but xylem bundles change position, and each rotates till it lies on the inner side

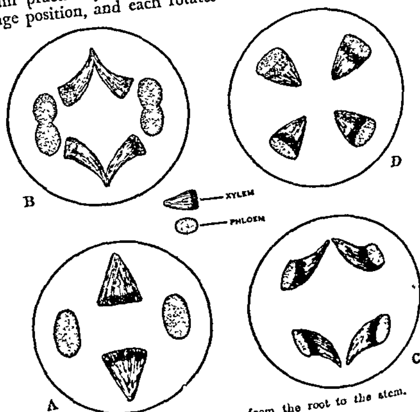


Fig. 446. Transitional stages from the root to the stem.

of the adjacent phloem bundle. As the xylem bundles undergo this transition they twist round so that the centripetal (exarch) xylem in the root now becomes centrifugal (endarch) in the stem. This transition has been found to take place in the

region which is neither a typical root nor a typical stem, and that region is the hypocotyl.

Origin of Lateral Roots (fig. 447). Lateral roots originate from an inner layer; so they are said to be *endogenous*. The inner layer is the pericycle. The cells of the pericycle lying against the protoxylem begin to divide tangentially, and a few

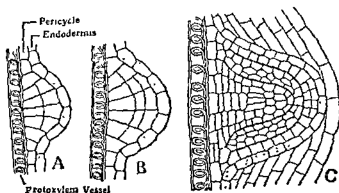


FIG. 447. Origin of a lateral root. *A*, *B* and *C* are stages in its formation from the pericycle.

layers are thus cut off. They push the endodermis outwards and tend to grow through the cortex. At this stage the three regions of the root-apex, namely, dermatogen (or calyptrogen), periblem and plerome, become well marked out. The endodermis and some of the cells of the cortex form a part of the root-cap, but as the root passes through the soil this portion soon wears off, and the root-cap is renewed by the calyptrogen.

Differences between Rootlets and Root-hairs. *Structural.* (1) Root-hairs are always unicellular; while the rootlets are always multicellular and complex, and provided with vascular strands and a root-cap. (2) In section the rootlet resembles a true root in all respects; while the root-hair is only a single cell. (3) Rootlets are endogenous in their origin, developing from the pericycle: but root-hairs are exogenous, developing as mere outgrowths from the individual cells of the epiblema. (4) Root-hairs are distributed over the tender parts of the root a little behind the root-cap; but the rootlets develop from any part of the root above the region of root-hairs. *Physiological.* Physiologically root-hairs absorb moisture and dissolved mineral salts from the soil by the process of osmosis; while the rootlets conduct the absorbed solution upwards into the main root and thence into the stem; they also help to fix the plant in the soil.

CHAPTER VI

INTERNAL STRUCTURE OF LEAVES

I. Dorsiventral Leaf (fig. 448)

Leaves generally grow in a horizontal direction with distinct upper and lower surfaces, the upper being more strongly illuminated than the lower. Such leaves are said to be **dorsiventral** (*dorsum*, back, *venter*, belly or front). This unequal illumination induces a difference in the internal structure between the upper and the lower surfaces of the leaf. A section made at a right angle to one of the veins reveals the following structure:

1. **Upper Epidermis.** A single layer of cells with a thick cuticle which checks excessive evaporation of water from the surface. It does not contain chloroplasts or stomata.

2. **Lower Epidermis.** Similarly a single layer but with thin cuticle. It is, however, interspersed with numerous stomata, the two guard cells of which contain some chloroplasts; none are present in the epidermal cells. Internal to each stoma a large cavity, known as the *respiratory cavity*, may be seen. The lower epidermis of the leaf is meant for the exchange of gases (oxygen and carbon dioxide) between the atmosphere and

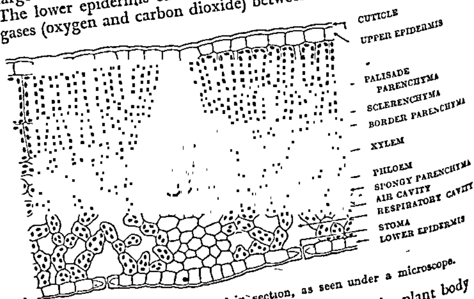


FIG. 448. A dorsiventral leaf in section, as seen under a microscope.

the plant body. Excess of water contained in the plant body also evaporates mostly through the lower epidermis.

3. **Mesophyll.** The ground tissue lying between the upper epidermis and the lower one is known as the mesophyll. It is differentiated into (1) **palisade parenchyma** and (2) **spongy parenchyma.**

(1) **Palisade parenchyma** consists of usually one to two or three layers of elongated, more or less cylindrical cells, closely packed with their long axes at right angles to the epidermis. They contain numerous chloroplasts which are arranged alongside the cell-walls. The function of palisade parenchyma as a whole is to manufacture sugar and starch in the presence of sunlight, i.e. during the day, with the help of the chloroplasts contained therein.

(2) **Spongy parenchyma** consists of oval, rounded, or more commonly irregular cells, loosely arranged towards the lower epidermis, enclosing numerous, large, intercellular spaces and air-cavities. They, however, fit closely around the vein or the vascular bundle. The cells contain a few chloroplasts. Spongy cells help diffusion of gases through the empty spaces left between them; they manufacture sugar and starch to some extent only.

4. **Vascular Bundles.** As they pass from the base of the leaf-blade towards its apex or margin they get reduced in size as well as in the number of their elements. Each vascular bundle (vein) consists of xylem towards the upper epidermis and phloem towards the lower. **Xylem** consists of various kinds of vessels (particularly annular and spiral), tracheids, wood fibres and wood parenchyma. Towards the apex of the vein xylem is represented by only a few narrow annular and spiral tracheids, or even by a single spiral tracheid; other elements disappear. Xylem conducts and distributes the water and the raw food material to different parts of the leaf-blade. **Phloem** consists of some narrow sieve-tubes, companion cells and phloem parenchyma. Towards the apex a few undeveloped sieve-tubes with companion cells may be seen. Phloem carries the prepared food material from the leaf-blade to the growing and storage regions.

The vascular bundles of petioles and larger veins are usually surrounded by **sclerenchyma sheath** consisting of rather thick-walled, fibrous cells which add to the strength of the vascular bundles. The sclerenchyma may completely surround each vascular bundle or it may be restricted to the upper or lower side or both as one or two separate patches. With decrease in the size of vascular bundles there is a corresponding reduction in the amount of sclerenchyma until in the smaller bundles

it disappears. Each bundle is surrounded by a layer of colourless parenchymatous cells usually known as the **border parenchyma** or **bundle sheath.**

The distribution of **sclerenchyma** is very irregular in leaves; sometimes it forms patches here and there in the ground tissue ; at other times it forms a continuous zone connecting two or more vascular bundles, or it extends from the epidermis, upper or lower, to the bundles. More frequently it occurs as a patch lying associated with xylem or phloem, or as a sheath, thicker on the upper and lower sides, encircling a vascular bundle.

II. Isobilateral Leaves (figs. 449-50)

In many monocotyledons the leaves are nearly erect, and so they are more or less equally illuminated on both sides. Such leaves are said to be **isobilateral** (*isos*, equal; *bi*, two; *lateris*, side).

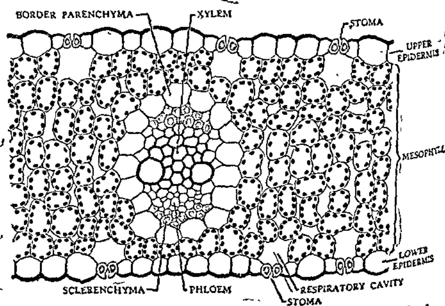


FIG. 449. An isobilateral leaf (a lily leaf) in section, as seen under a microscope.

They show a uniform structure on both sides. The epidermis on either side contains stomata, and the mesophyll is often not differentiated into palisade and spongy parenchyma, but consists of spongy cells only, in which the chloroplasts are evenly distributed. Instead of spongy cells the mesophyll may consist of palisade cells only, as in the shade plants.

Sometimes the mesophyll may be differentiated into spongy parenchyma in the centre and palisade parenchyma on either side.

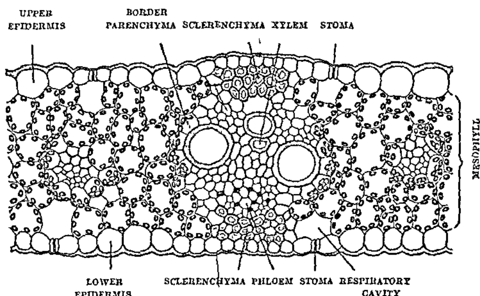


FIG. 450. An isobilateral leaf (maize leaf) in section, as seen under a microscope.

CHAPTER VII

SECONDARY GROWTH IN THICKNESS

I. Dicotyledonous Stem

In perennial dicotyledons (shrubs and trees) after the primary tissues are fully formed, the **cambium** becomes active and begins to cut off new (secondary) tissues in the stelar region. Sooner or later another strip of meristem, the **cork-cambium**, makes its appearance in the peripheral region and begins to form other secondary tissues, viz. cork, etc., in that region. All these secondary tissues are added on to the primary ones, and as a result the stem increases in thickness. *This increase in thickness, due to the addition of secondary tissues cut off by the cambium and the cork-cambium in the stelar and extra-stelar regions respectively, is spoken of as* **secondary growth.**

A. Activity of the Cambium

Cambium Ring. It is seen that some of the medullary ray cells, mostly in a line with the **fascicular cambium** (i.e. the cambium of the vascular bundle), become meristematic and

form a strip of **interfascicular cambium** (i.e. the cambium in between two vascular bundles). This joins on to the fascicular cambium on either side and forms a complete ring known as the cambium ring.

Secondary Tissues. The cambium ring as a whole becomes actively meristematic and gives off new cells both externally and internally. Those cut off on the outer side are gradually modified into the elements of phloem; these constitute the **secondary phloem.** The secondary phloem consists of sieve-tubes, companion cells and phloem parenchyma and often also some bands or patches of bast fibres.

The new cells cut off by the cambium on its inner side are gradually modified into the various elements of xylem; these constitute the **secondary xylem.** The secondary xylem consists of scalariform and pitted vessels, tracheids, numerous wood fibres arranged mostly in radial rows, and some wood parenchyma. The cambium is always more active on the inner side than on the outer. Consequently xylem increases more rapidly in bulk than phloem, and soon forms a compact mass. As a matter of fact the secondary xylem forms the main bulk of the plant body after secondary growth. In consequence of continued formation of secondary xylem and the pressure exerted by it the cambium, phloem and the surrounding tissues are gradually pushed outwards, and for the same reason some of the primary tissues get crushed. The primary xylem, however, remains more or less intact in or around the centre.

Here and there the cambium forms some narrow bands of parenchyma, radially elongated and passing through the secondary xylem and the secondary phloem; these are the **secondary medullary rays.** They are one, two or a few layers in thickness, and one to many layers in height.

(Note that the secondary medullary rays develop from the cambium and that they remain confined to secondary xylem and secondary phloem; whereas the primary medullary rays originate from the apical meristem and extend from the pith to the pericycle. Both carry on the function of conduction of water and food materials outward to the peripheral tissues).

Annual Rings (figs. 451-2). In regions where climatic variations are of pronounced nature the activity of the cambium is not uniform throughout the year. In spring or during active vegetative season with greater production and activity of foliage leaves, the need of transport of sap is acute, and hence at this time of the year the cambium is more active and forms a greater number of vessels with wider cavities (large pitted vessels). In winter or during inactive period

however, when there is less demand for transport of sap, the cambium is less active and forms elements of narrower dimensions (narrow pitted vessels, tracheids and wood fibres). The wood thus formed in the spring is called the **spring wood** or early wood, and that formed in winter is called the **autumn wood** or late wood. These two kinds of wood appear together, in a transverse section of the stem, as a concentric ring known as the **annual ring or growth ring**, and successive annual rings are formed year after year by the activity of the cambium. There is a sharp contrast between the late autumn wood and the early spring wood, and this makes the successive rings distinct even to the naked eye. Annual rings are readily seen with the naked eye in the trunk of a tree which has been cut down transversely (fig. 451). Each annual ring corresponds to one year's growth, and by counting the total number of annual rings the age of the plant can be approximately determined, as in pine. The number of annual rings may, however, vary in many plants. In some trees large spring vessels are arranged more or less in a ring; while in others they are distributed more or less uniformly throughout the whole spring wood. Annual rings of successive years may vary greatly in width. Wide rings are formed under favourable conditions of growth of the tree, and narrow ones are formed when conditions are unfavourable.



FIG. 451. Cut surface of a stem showing annual rings.



FIG. 452. An annual ring in section (magnified).

Heart-wood and Sap-wood. In old trees the central regic of the secondary wood is filled up with tannin and other su stances which make it hard and durable. This region known as the **heart-wood** or **duramen.** It looks black, owing t the presence of tannins, oils, gums, resins, etc., in it. Th vessels often become plugged with *tyloses* (see fig. 459), whic are balloon-like ingrowths, developing from the adjoinin parenchyma, through the pits. The function of the hear wood is no longer conduction of water, but it simply give mechanical support to the stem. The outer region of th secondary wood which is of lighter colour is known as th **sap-wood** or **alburnum,** and this alone is used for conductio of water and salt solutions from the root to the leaf.

B. Origin and Activity of the Cork-cambium

The formation of new tissues by the cambium exerts a considerable pressure on the peripheral tissues of the stem. The epidermis becomes considerably stretched and gets ruptured here and there, often breaking down altogether. Sclerenchyma and collenchyma become much flattened tangentially. Cortex is also similarly affected but it persists for a long time because of the elastic nature of the cell-walls and the power of accommodation of its cells. To replace or to reinforce the peripheral protective tissues, particularly the epidermis, a strip of secondary meristem, called the **cork-cambium** or **phellogen** (*phellos*, cork; *genes*, to form) arises in that region for better protection at secondary stage. The cork-cambium commonly originates in the outer layer of collenchyma. It may also arise in the epidermis itself, or in the deeper layers of the cortex. In the formation of the cork-cambium the outer layer of collenchyma becomes meristematic; it divides and forms into a thin strip of cork-cambium consisting of a few rows of narrow, thin-walled and roughly rectangular cells; the latter are living and active. The cork-cambium takes on meristematic activity and begins to divide and give off new cells on both sides, forming the **secondary cortex** on the inner side and the **cork** on the outer side.

Secondary Cortex.
are parenchymatous in
cortex or phelloderm. Th[illegible] Sometimes contain chloroplasts and carry on photosynthesis. Sometimes they are thick-walled, but made up of cellulose and provided with pits. The cells of the secondary cortex are arranged in a few rows, and are added on to the primary cortex.

Cork. The new cells cut off by the cork-cambium on its outer side are roughly rectangular in shape and soon become suberized. They form the **cork or phellem** of the plant. The

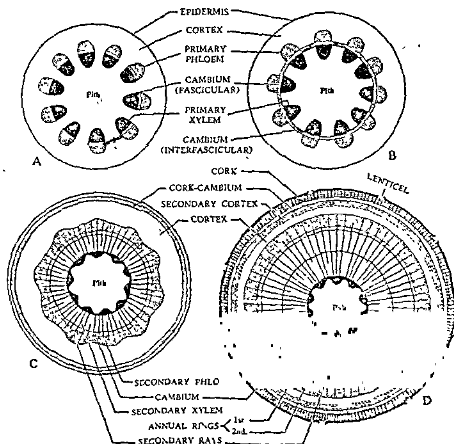


FIG. 453. Diagrams showing stages in the secondary growth of a dicotyledonous stem up to two years.

cork tissue of cork oak (*Quercus suber*), a Mediterranean plant, is of considerable thickness, and is the source of bottle cork. When this is removed from the tree a fresh strip of cork is produced by the underlying cork-cambium. Cork cells are dead, suberized and thick-walled. They are arranged in a few radial rows, without leaving intercellular spaces between them. and are usually brownish in colour. Being suberized the cork is impervious to water, and it thus cuts off the outer tissues from the supply of water and food material. Consequently, they soon die off and act as the bark of the plant.

All the new tissues formed at the peripheral region, viz. the cork or phellem, the cork-cambium or phellogen and the secondary cortex or phelloderm, are together known as the periderm.

Bark. All the dead tissues lying outside the active cork-cambium constitute the bark of the plant. It, therefore, in-

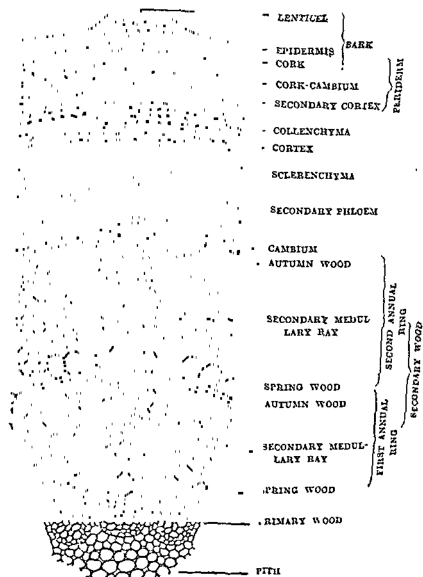


FIG. 454. A two-year old dicotyledonous stem (a sector) in transection showing secondary growth in thickness.

cludes the epidermis, lenticels and cork, and sometimes also hypodermis and a portion of the cortex, depending on the position of the cork-cambium, that is, the deeper the origin of the cork-cambium the thicker is the bark.

When the cork-cambium appears in the form of a complete ring the bark that is formed comes away in a sheet; such a bark is known as the ring-bark, as in *Betula* (B. BHURJJA-PATRA); and when it appears in strips the resulting bark

comes away in the form of scales; such a bark is, therefore, known as the **scale-bark,** as in guava. The function of the bark is protection (see p. 271).

Lenticels (fig. 455). These are aerating pores formed in the bark, through which exchange of gases takes place. Externally they appear as scars or small protrusions on the surface of the stem. A section through one of the scars shows that the lenticel consists of a loose mass of small, thin-walled cells **(complementary cells).** At each lenticel the cork-cambium, instead of producing compact rows of cork cells, usually forms oval, spherical or irregular cells which are very loosely arranged, leaving a lot of intercellular spaces between them. The lenticel commonly develops below a stoma, and as its cells increase in number and size the epidermis gets ruptured. Communication is thus established between the atmosphere and the internal tissues of the plant. The gases can then easily pass in and out through the lenticel. To facilitate the diffusion of gases empty spaces are left between the different rows, upper and lower, of the cork and the cork-cambium. The lenticel may be closed in winter by the formation of cork; this, however, gets ruptured as the new active season begins.

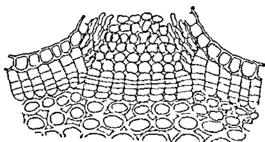


FIG. 455. A lenticel, as seen in transection.

Tissues in Pr. Structure	Meristematic Tissues	Tissues in Sec. Structure
Epidermis ...	... ...	1 Bark (a) Epidermis (b) Lenticels (c) Cork
Collenchyma ⟶	Cork cambium ⟶	2. Cork-cambium 3. Secondary cortex
...	... ...	4. Collenchyma
Primary cortex	.. ...	5. Primary cortex
Endodermis	... ...	6. Endodermis
Pericycle	... ...	7. Pericycle (sclerenchyma)
Medullary rays ⟶	Interfascicular cambium	
Primary phloem	... ↓	(gets crushed)
		8. Secondary phloem
Cambium ⟶	Cambium ring ⟶	9. Cambium ring 10. Sec. wood (annual rings) (a) Spring wood (b) Autumn wood 11. Sec. medullary rays
Primary wood	.. ...	12. Primary wood
Pith ...	... ...	13. Pith

II. Dicotyledonous Root

As in the stem the secondary growth in thickness of th root is due to the addition of new tissues cut off by the cam bium and the cork-cambium in the interior as well as in th peripheral region. In the root the secondary growth com mences a few centimetres behind the apex.

A. *Origin and Activity of the Cambium*

The conjunctive tissue just flanking the phloem on its inner side becomes meristematic and by dividing gives origin to a strip of cambium. It is evident that there are as many strips of cambium as there are phloem bundles. The cells of the conjunctive tissue lying in between xylem and phloem bundles also become meristematic so that the strips of cambium are seen to extend outwards between phloem and xylem. Then the portion of the pericycle abutting on the protoxylem becomes meristematic; it divides and forms a strip of cambium there, joining with the earlier-formed cambium strips on either side of xylem. Thus a continuous wavy band of **cambium** is formed, extending over the xylem and down the phloem. The secondary growth then commences with the activity of this cambium band. The portion of the cambium adjoining the inner phloem becomes active first. It begins to cut off new cells on both sides, but more profusely on the inside. As a result of this increased formation of new cells on the inner side the cambium and the phloem are gradually pushed outwards. The wavy band of cambium soon becomes circular or ring-like. The whole of the cambium ring then becomes actively meristematic, and

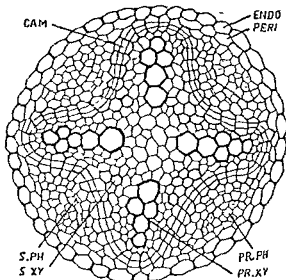


FIG 456. Secondary growth of dicotyledonous root (early stage). *CAM*, cambium; *ENDO*, endodermis; *PERI*, pericycle; *PR.PH*, primary phloem; *PR XY*, primary xylem; *S.PH*, secondary phloem; *S.XY*, secondary xylem.

behaves in the same way as in the stem, giving rise to secondary xylem on the inside and secondary phloem on the outside.

Secondary Xylem. The new cells cut off by the cambium on the inner side gradually become differentiated into the elements of xylem and all these new elements together constitute the secondary xylem. The cambium is always more

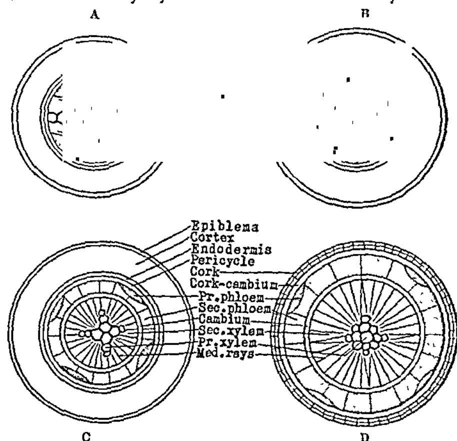


FIG. 457. Diagrams showing stages in the secondary growth of a dicotyledonous root

active on the inner side than on the outer, and consequently secondary wood increases more rapidly in bulk than secondary phloem; in fact, the secondary wood forms the main bulk of the plant body after secondary growth. It is made of numerous large vessels with comparatively thin walls, abundance of wood parenchyma, but few wood fibres. As more wood is added, the cambium and phloem are gradually pushed farther out. As the root lies underground it is not subjected to variations of aerial conditions; consequently annual rings, which are so characteristic of woody stems, are rarely formed in the root. Even when the root has increased considerably in

thickness the primary xylem bundles still remain intact and can be recognized under the microscope in several cases. Against the protoxylem the cambium forms distinct and widening radial bands of parenchyma, which constitute the **primary medullary rays.** These extend up to the secondary phloem Other smaller and thinner medullary rays are also formed later by the cambium. Medullary rays are larger and more prominent in the root than in the stem.

Secondary Phloem. The new elements cut off by the cambium on the outer side become gradually modified into the elements of phloem, and all these together constitute the secondary phloem. It consists of sieve-tubes with companion cells and abundant parenchyma. but less bast fibres (except

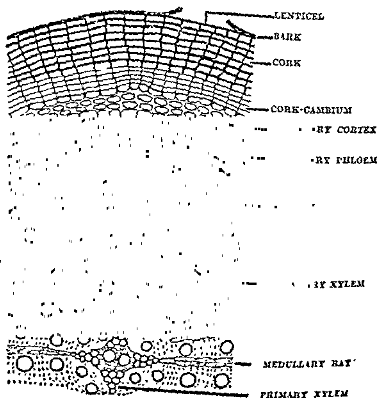


FIG. 458. Secondary growth of dicotyledonous root (later stage).

in special cases). The secondary phloem is much thinner than the secondary xylem. The primary phloem soon gets crushed.

B. Origin and Activity of the Cork-cambium

When the secondary growth has advanced to some extent the single-layered pericycle as a whole becomes meristematic and divides into a few rows of thin-walled, roughly rectangular cells; these constitute the **cork-cambium** or **phellogen.** The

cork-cambium may also arise, in some cases, in the phloem. As in the stem, it produces a few brownish layers of **cork or phellem** on the outside, and the **secondary cortex** or **phelloderm** on the inside. The secondary cortex of the root does not contain chloroplasts. The **bark** *of the root is not extensive ; it forms* only a thin covering. The cortex, being thin-walled, is very much compressed and ultimately it gets disorganized, and *sloughs off. Such is also the fate of the endodermis. Epiblema* dies out earlier. Here and there **lenticels** may be developed, as in the stem.

Functions of Cork and Bark. Cork and bark are the protective tissues of plants. They are meant to check evaporation of water, to guard the plant body against variation of external temperature, and to protect it against the attack of parasitic fungi and insects.

1. **Cork.** *Sooner or later, in shrubs and trees, the epidermis is reinforced or sometimes replaced by the cork which* then takes on the functions of the former, being essentially a protective tissue. The cork is always much thicker than the epidermis, and as such, it can afford greater protection than the epidermis. The renewal of the cork by the underlying cork-cambium is a decided advantage in this respect. All the cork cells are suberized, and thus the cork acts as a waterproof covering to the stem. Loss of water by evaporation is, therefore, prevented or greatly minimized. The cork tissue also protects the plant against the attack of parasitic fungi and insects. Cork cells, being dead and empty containing air only, are bad conductors of heat. This being so, sudden variation of outside temperature does not affect the internal tissues of the plant. Cork is also made use of by the plant for the healing of wounds.

2. **Bark.** Since bark is a mass of *dead tissues lying in the peripheral region of the plant body as a hard dry covering,* its function is protection. It protects the inner tissues against the attack of fungi and insects, against loss of water by evaporation, and against the variation of external temperature. In many plants the bark sloughs off, and then all these functions are carried on by the cork part only.

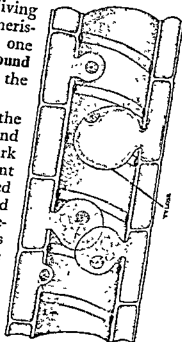
Protective Tissues. It is to be noted that there are three tissues in plants, namely, (1) the **epidermis,** (2) the **cork,** and (3) the **bark,** which develop for the specific purpose of protection. At an early stage of the plant the epidermis alone affords the necessary protection, but in shrubs and trees at a later stage the epidermis becomes reinforced or even replaced by the cor^k

and the bark for the same purpose. The functions of the epidermis have been discussed on page 230 and those of the cork and the bark discussed on page 271.

CHAPTER VIII
HEALING OF WOUNDS AND FALL OF LEAVES

Healing of Wounds. In the cases of simpler wounds, the wounded cells die and dry up, while outer walls or cells of the underlying uninjured layers become impregnated with protective substances.

In the cases of larger wounds, the outermost uninjured layer of living parenchymatous tissue forms a meristem (phellogen) which produces one or more layers of cork—the **wound cork**; the cork then protects the wounded surface.



Frequently in woody plants the uninjured cells adjoining the wound do not directly produce the cork tissue, but give rise to a succulent mass of parenchymatous cells, called the **callus.** This callus fills up and covers the wound, and not infrequently it overgrows the latter. This explains the origin of knots in some trees. If the cambium is injured the cells of the callus often form a fresh strip of cambium which becomes connected with the original cambium.

Sometimes, instead of any fresh layer being formed, the tracheae or wood vessels develop tracheal plugs, called **tyloses** (fig. 459), which are balloon-like ingrowths developing from the adjoining parenchyma through pits. Tyloses plug the lumen of the vessels, while other elements simply dry up. Latex, if present, coagulates. In this way loss of water is prevented from the exposed surface.



FIG. 459. Vessel with tyloses.

Fall of Leaves. In deciduous trees and shrubs the leaf falls in the dry season, when the absorption of water by roots

is minimized and evaporation of water from the surfaces of leaves is enhanced. Both the conditions prevail in winter or in a prolonged dry summer and, therefore, the leaf is seen to fall at that time. The immediate structural cause of the leaf-fall is the formation of a layer of cork across the base of the petiole and the development of a well-defined *separation layer*, called the **absciss-layer,** just external to the cork. The living parenchymatous cells lying across the base of the petiole, and also those of the vascular bundles, become meristematic and form a layer of cork, or these living cells become suberized directly, forming the cork layer without any division. In

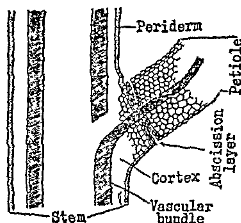


FIG. 460

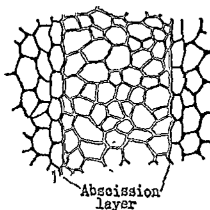


FIG. 461

Fig. 460. Formation of abscission layer at the base of the leaf. Fig. 461. A portion of the abscission layer in surface view sometime before leaf-fall.

either case this cork is later reinforced by a fresh strip of cork formed by the underlying cork-cambium. In some cases the cork-cambium directly produces a few layers of cork at the base of the petiole. The cork being suberized and the vessels getting constricted owing to the lateral pressure of the cork, the leaf is cut off from the supply of water; it dries up and dies. The separation layer, or the absciss-layer, lying just external to the cork, turns yellowish and gets disorganized. Cellulose of this layer becomes converted into pectin which dissolves, and thus the cells become separated from one another. The leaf then remains supported by the vessels only, and it breaks off mechanically at the absciss-layer, either under its own weight or when disturbed by the wind. The vessels are clogged with gum and tyloses, and the exposed surface is covered with cork. Thus exudation of sap is prevented. When the leaf falls, a scar is left on the stem; this is called the **leaf-scar.**

PART III
PHYSIOLOGY

CHAPTER I
GENERAL CONSIDERATIONS

Physiology deals with the various functions of life such as the construction of food, nutrition of the protoplasm, building up of the body, respiration, metabolism, reproduction, growth, movements, and so on. All these vital functions are carried on by the protoplasm—the living substance—in both plants and animals. To maintain the life and activity of the protoplasm the primary requirements are **water, air, food, heat** and **light**.

Water. Water (see also p. 15) is indispensable to the protoplasm for its manifold activities. There is always a high percentage of water—75-95 per cent—associated with the protoplasm in its active state. Besides, inorganic materials are absorbed from the soil in a state of dilute solution; prepared food travels in the plant through the medium of water; gases similarly reach the protoplasm in solution; and many chemical changes are also carried out in solution in the plant body.

Air. Air is another necessity of the plant. Of the gases present in the air the plant normally utilizes only oxygen and carbon dioxide. The plant requires oxygen for respiration and carbon dioxide for manufacture of food. For respiration oxygen of the air is taken in and an almost equal volume of carbon dioxide given out, and this process continues day and night in all the living cells. On the other hand, for the manufacture of food the carbon dioxide of the air is taken in and an almost equal volume of oxygen given out (H_2O, and not CO_2, being the source of this oxygen), and this process is carried on only by the green cells in the presence of sunlight.

Food. Protoplasm also requires food for its nutrition. This is of primary importance to all living organisms; but unlike animals, plants manufacture their own food from the raw food material—water and inorganic salts absorbed from the soil and carbon dioxide absorbed from the air.

Heat. A certain amount of heat is necessary to maintain the activity of the protoplasm, and for all the vital processes

carried on within the plant body. Within certain limits the higher the temperature the greater is the activity of the protoplasm. For different functions different temperatures are necessary. Generally speaking, the maximum temperature may be stated to be 50°C., with the optimum lying a little over 30°C.

Light. Sunlight is the original source of energy and it has a stimulating effect on growth; it makes the plant sturdy. It is not, however, essential in the early stages of growth. Light is an important factor responsible for green colouration of the plant, utilization of carbon dioxide of the air and manufacture of sugar and starch. It is also responsible for some kinds of movement of plant organs.

Physiology may be divided into (A) **physiology of nutrition or chemical physiology,** (B) **physiology of growth and movements,** and (C) **physiology of reproduction.**

A. PHYSIOLOGY OF NUTRITION OR CHEMICAL PHYSIOLOGY

CHAPTER II

SOILS

Since water and mineral salts are almost exclusively obtained from the soil for their utilization later in the plant body a knowledge of soil science in different aspects is an essential pre-requisite to the study of plant physiology.

Soil Formation. Soils are formed by the disintegration and decomposition of rocks due to weathering (action of rain-water, running streams, glaciers, wind, alternate high and low temperatures, etc.) and the action of soil organisms such as many bacteria, fungi, protozoa, earthworm, etc., and also interactions of various chemical substances present in the soil. Although soils are normally formed from underlying rocks in a particular region, these may be transported to long distances by agencies like rivers, glaciers, strong wind, etc.

Physical Nature. Physically the soil is a mixture of mineral particles of varying sizes—coarse and fine—of different degrees, some angular and others rounded, with certain amount of decaying organic matter in it. The soil has been graded into the following types according to the size of the particles:

Coarse particles	...	2 - ·2 mm. form *coarse sand*
Smaller particles	...	·2 - ·02 mm. form *sand*
Finer particles	...	·02-·002 mm. form *silt*
Very fine particles	...	less than ·002 mm. form *clay*

The property of the soil (both physical and chemical) is largely determined by the proportion of clay in it. On this basis soils are classified into (1) **sandy soil** containing more or less 10% each of clay and silt with a large proportion of sand; (2) **loam** containing more or less 30% each of clay and silt, the rest being sand; and (3) **clay soil** containing more than 30% of clay. **Clay soil** is badly aerated and it becomes easily water-logged. It has a great capacity for retaining water, particles being very fine. Drainage in this soil is difficult, while capillarity increases considerably. It is heavy and easily becomes compact, and cracks when dried up. A considerable amount of plant food is, however, available in this soil. **Sandy soil** on the other hand is always [illegible] allows easy percolation [illegible] it quickly dries up and [illegible] in this soil. This soil is always light. **Loam** is the best soil for vigorous plant growth and is most suitable for agricultural crops because all the important physical conditions are satisfied—porosity for better aeration, percolation for downward movement of excess water, and capillarity for upward movement of sub-soil water. At the same time it is rich in plant food. The proportions of the above constituents of the soil can be approximately determined by stirring a small lump of soil in a beaker to which an excess of water has been added, and then pouring the contents into a measuring cylinder. When allowed to settle it is seen that sand particles collect at the bottom, silt higher up, and clay on the top in distinct layers. A portion of the clay, however, remains suspended in water. Their proportions are then determined and percentages calculated. Humus mostly floats on water. The water may be tested for acidity or alkanity with litmus papers.

Chemical Nature. Chemically the soil contains a variety of *inorganic salts* such as nitrates, sulphates, phosphates, chlorides, carbonates, etc., of potassium (K), calcium (Ca), magnesium (Mg), sodium (Na) and iron (Fe), and of the 'trace' elements like boron (B), manganese (Mn), copper (Cu), zinc (Zn), aluminium (Al), molybdenum (Mo), etc. Many of the elements, however, occur in the soil in the form of oxides, often in very low percentages—less than 1; 'trace' elements mostly occur in .002—.0001%. Further, many of these remain in the soil in a variety of complex chemical forms and are not

available to plants. It is only the simple forms that are absorbed by plants in very dilute solutions as raw food material. In the absence of any of the required compounds the plant suffers. In nature, however, the nutrient salts are very widely distributed. A certain amount of *organic compounds,* chiefly proteins and their decomposition products, derived from the waste products of animals and dead bodies of plants and animals as a result of oxidation by soil bacteria and fungi, are present in the soil. *Humus* (decaying organic matter formed in the soil from shed leaves and other dead parts of plants as a result of bacterial and fungal activities) contains a certain amount of organic food (see p. 278). *Acidity* or *alkalinity* of the soil is no less important for plant growth than the availability of plant food in the soil. Soils containing a high amount of lime (calcium carbonate) are alkaline, and soils containing a high quantity of humus are acid. These conditions can, however, be altered by the addition of one or the other, as the case may be. Most of the field crops prefer a slightly acid soil. Some grow well in the neutral soil, while a few like banana prefer an acid soil. The soil containing a certain amount of lime (calcium carbonate) is said to be calcareous soil. The presence of calcium carbonate in such a soil can be detected by adding strong hydrochloric acid to a small sample of it when effervesence is noticed in it either with naked eyes or under a pocket lens.

Soil Water. Soil contains a varying amount of water with a certain amount of various chemical compounds dissolved in it—inorganic compounds being derived principally from rocks, and organic compounds derived from plant and animal residues. Thus availability of soil water, rather soil solution, is of primary importance (see p. 290).

Soil Air. The air, evidently containing a fairly large proportion of oxygen, present in the interspaces of soil particles is very important as it helps normal respiration of roots and the various soil organisms such as aerobic bacteria, fungi, protozoa, earthworm, etc., and maintains their activity. In a clogged soil with the preponderence of clay such organs and organisms suffer.

Soil Organisms. Various kinds of bacteria are present in the soil, sometimes to the extent of a few million individuals per gram of soil, particularly in the region of organic matter, and many of them are useful agents of soil fertility. Thus nitrifying bacteria convert proteins of dead plants and animals into nitrates, and it is a fact that but for the activity of such

bacteria the proteins would have remained locked up in the soil as such without any utility. Then there are nitrogen-fixing bacteria, ammonifying bacteria, sulphur bacteria and a host of other types in the soil. Fungi are also abundant in the soil, particularly in the acid soil replacing bacteria. Like the bacteria they are also useful agents in decomposing proteins. Many algae are also present in the soil. It is now definitely known that many of the blue-green algae fix atmospheric nitrogen in the soil. Among animals the soil-dwellers like many protozoa, earthworms, rats, etc., are useful agents in altering the soil. The burrowing animals make the soil loose for better aeration and percolation of water.

Humus. Humus is a dark-coloured substance present in many soils. It consists of organic matter, mainly cellulose and lignin combined with proteins, in various stages of decomposition in the soil, derived from dead roots, trunks, branches and leaves, under the action of various types of soil bacteria and fungi. Humus usually forms a surface layer, sometimes of some depth, as in forests and swamps. It is of considerable importance to plants both chemically and physically. The nitrogenous organic compounds of the humus are acted on by various bacteria and fungi and finally converted into nitrates which are absorbed by plants. Humus, therefore, is a source of plant food. Physically, however, it is more important since it gives the soil a loose texture ensuring better aeration, and being colloidal in nature like clay particles it has also a great capacity for imbibing and retaining water. Thus, added to sandy soil it increases the water-holding capacity of it, and added to clay soil it loosens the compactness of it and increases porosity for better aeration. Soil containing 5-15% of humus is suitable for agricultural crops. It is the seat of most of the bacterial processes in the soil.

Fertilizers. Ordinarily the soil contains the necessary salts required by plants. Deficiency, however, sometimes occurs in one or more of them, and to make good this deficiency the use of fertilizers or manures becomes a necessity. Fertilizers are certain chemical substances which when properly added to the soil make it fertile, i.e. enable it to produce more abundantly. Manuring of the field for better crop production may be done by any of the following three methods. (1) Artificial manuring is done by introducing into the soil particular chemical compounds or their mixtures in suitable proportions. Generally the soil becomes deficient in potash, phosphorus and nitrogen ; so soluble compounds of these elements are used as

fertilizers. (2) Farmyard manuring is done by adding cow-dung and organic refuses to the soil. (3) Natural manuring is done by rotation of crops (see pp. 288-9).

Sulphate of ammonia is now extensively used as a chemical fertilizer for many of the field crops like rice, barley, potato, sugarcane, tea, orange, cabbage, cauliflower, turnip, mustard etc. This chemical becomes quickly nitrified in the soil in course of a few days and changed to calcium nitrate. It, however, makes the soil acid and, therefore, unsuitable for many crops. The remedy, however, lies in adding lime to the soil. Ammonium sulphate is not washed out of the soil even by torrential rains. Nitrate of soda is also another source of nitrogen for field crops

CHAPTER III

CHEMICAL COMPOSITION OF THE PLANT

The various elements that have entered into the composition of the plant body may be determined by **chemical analyses**, and those essentially required by the plant determined by **water culture experiments.**

I. Chemical Analyses

By chemical analyses of a plant we can find out the various elements that have entered into its composition. For this purpose a representative sample of the plant is taken and it is dried at 110°C. or so. All the water that the plant contains is thus driven off. Then, by careful weighing, the proportion *of water to the total weight of the plant is determined. Plants* in general are found to contain a high percentage of **water**—in woody parts about 50 per cent, in soft parts about 75 per cent, in succulent parts from about 85 to 95 per cent, and in water plants 95 to 98 per cent. When the plant is *charred* we get charcoal. The main bulk of this charcoal is **carbon**; in fact, almost half the dry weight of the plant is carbon. The dried plant is then carefully burnt over a flame at a temperature of about 600°C. On thus burning, the **organic compounds** such as the proteins, carbohydrates, fats and oils, etc., being combustible, are converted into carbon dioxide, water vapour, sulphur dioxide and ammonia or free nitrogen, and escape as such. These gases may be collected by proper methods and their composition studied. *Proteins* when analysed are seen to contain **carbon** (C), **hydrogen** (H), **oxygen** (O), **nitrogen** (N), and often **sulphur** (S), and **phosphorus** (P); *carbohydrates* and *fats and oils* contain only the first three elements. The residue left after the above treatment consists only of **inorganic compounds** which are incombustible, and is known as **ash.**

The percentage of ash varies greatly in different plants and also in different parts of the same plant, usually lying within the range of 1%—15%. Analyses of the ash show that, of the 92 well-known chemical elements occurring in nature, about 40, possibly more, are present in it. Most of these elements occur in very minute quantities and their presence too is not very constant. The following, however, are constantly found in the ash of the plant, occurring of course in varying proportions in different plants: potassium (K), calcium (Ca), magnesium (Mg), iron (Fe) and sodium (Na) among the metals, and sulphur (S), phosphorus (P), chlorine (Cl) and silicon (Si) among the non-metals. In addition certain other elements found in the ash in traces only are: boron (B), manganese (Mn), zinc (Zn), copper (Cu), molybdenum (Mo), aluminium (Al), etc; these are known as 'trace' elements (see p. 289).

Chemical analyses of the plant body (including the combustible material and the ash) show that, of the various elements present in it in easily detectable and measurable quantities, the following 13 elements are constant in all plants: potassium, calcium, magnesium, iron and sodium among the metals, and carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus, chlorine and silicon among the non-metals. Besides, some of the 'trace' elements which are now known to be constant in green plants are: boron, manganese, zinc, copper and molybdenum. Aluminium is also very widespread in plants. The average chemical composition of the plant body may be given thus:

Carbon	45·0%
Oxygen	42·0%
Hydrogen	6·5%
Nitrogen	1·5%
Ash	5·0%
	100%[1]

II. Water Culture Experiments

Water culture experiments are carried out to ascertain which elements are essentially required by plants for their normal growth, and which only incidentally absorbed. These experiments further help us to understand the forms (chemical compounds) in which they are best taken up, the particular concentration of the solute, and the source of supply (soil or air) of these elements. Water culture experiments consist in

[1] After Maximov.

growing some seedlings in water containing some known salts in particular proportions, known as **normal culture solution**, and studying the effect produced on them (seedlings) regarding growth and development. The following composition has been worked out by Knop as forming the normal water culture solution, that is, the solution required by the seedlings for their normal growth. Normal culture solutions of various other compositions are also used.

Knop's normal culture solution

Potassium nitrate, KNO_3 ...	... 1 gm.
Acid potassium phosphate, KH_2PO_4	... 1 gm.
Magnesium sulphate, $MgSO_4$	.. 1 gm.
Calcium nitrate, $Ca(NO_3)_2$ ...	... 4 gms.
Ferric chloride solution, $FeCl_3$	... a few drops
Water	... 1,000 c.c.

This is a stock solution of 0·7% strength. To make a 0·1% solution which is suitable for water culture experiments add 6,000 c.c. of water to the stock solution.

Experiment 1. Water culture experiments. A series of bottles or jars of the same size and shape are fitted each with a split cork. A number of seedlings of the same kind and more or less of the same size are taken. The bottles marked *A*, *B*, *C*, *D*, etc., are filled with culture solutions of known composition. Through the split cork a seedling is introduced into each bottle. The bottles are wrapped with black paper and exposed to light. Arrangements should be made for proper aeration of the roots. It is desirable that the culture solution should be renewed fortnightly. The following table shows the nature of solutions used and the effect produced on the seedlings.

A	with normal culture solution ...	Growth of the seedling is normal.
B	the same minus potassium salts	Growth becomes checked; leaves lose their colour; the seedling withers; and carbohydrate formation is slow.
C	the same minus calcium salts ...	Root system does not develop pro
D	the same minus magnesium salts	
E	the same minus iron salts ...	
F	the same minus phosphorus compounds.	Growth is slow and the seedling begins to weaken.
G	the same minus sulphur compounds	Leaves yellowish and stem slender.
H	the same minus nitrogen compounds.	Seedling is weak and straggling, and leaves yellowish.

Inference. Water culture experiments prove conclusively that a plant can grow satisfactorily only when it is supplied with K, Ca, Mg, Fe and H, O, N, S, P. These experiments thus help us to understand that these elements (together with C) are essential, while others are non-essential

being only incidentally absorbed; they show further that these elements are absorbed in soluble compounds, in suitable proportions and in very dilute solutions, occurring in the soil; that free oxygen and carbon dioxide are obtained from the air (and not from the soil)—oxygen for the respiration of the living cells and carbon dioxide for the manufacture of food by the green cells; that free nitrogen of the air is of no use to the plant; and that the plant must be exposed to light. Chemical analyses give us no clue to any of the above-mentioned facts

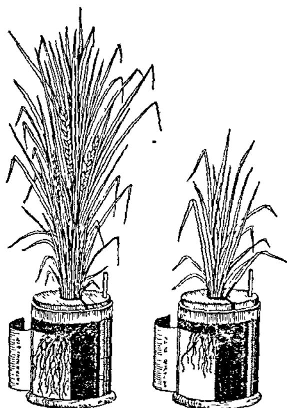


FIG. 462. Water culture experiments; *left*, in normal solution; *right*, in the same minus one of the essential elements.

Sand Culture Experiments. To obviate many difficulties in water culture experiments it has become the growing practice with scientists to take to sand or charcoal culture. Charcoal is thoroughly washed and powdered. In the case of sand, it is washed, dried and then ignited to remove organic impurities. Normal culture solution is added to any of the two media and growth of the seedling studied. The effect produced on the seedling under the exclusion of a particular element is studied in the same way as in water culture experiments

Essential and Non-essential Elements

Chemical analyses of the plant reveal the presence of a long list of elements in it, while water culture experiments prove that *ten* elements (including carbon which is obtained from the air) are essential for normal growth of all plants. Of the trace elements boron, manganese, zinc, copper and molybdenum are also now regarded as essential (see p. 289). Thus the total number of elements now considered essential are 15 (see list below). Other elements present in the plant body are non-essential. It should, however, be noted that certain plants require for their normal growth one or more elements other than the established 15 essential elements.

Classification of Elements

Essential: metals—K, Ca, Mg and Fe.
non metals—C, H, O, N, S and P.

Non-essential: metal—Na.
non-metals—Cl and Si.

Trace (essential): metals—Mn, Zn, Cu and Mo.
non-metal—B.

Role played by the Elements in the Plant Body

1. **Potassium.** It is abundantly present in the growing regions. It is essentially a constituent of the protoplasm and is closely connected with its vital activity. It is, however, absent from the nucleus and the plastids. Potassium is known to act as catalyst and helps the synthesis of carbohydrates and proteins; starch grains are not formed in the absence of potassium. Potassium helps the growth of the plant and enables it to produce healthy flowers, seeds and fruits. In the absence of potassium the growth of the plant is checked; the stem becomes slender and the leaves lose their colour and gradually wither. *Potassium nitrate and potassium chloride are the* usual forms in which potassium is absorbed by plants. Water lettuce (*Pistia*), when burnt, yields about 12% of potash, and is used as a valuable manure.

2. **Magnesium.** It helps in the synthesis of phosphorus-containing lipid substances which are important constituents of protoplasm. It is present in the chlorophyll to the extent of about 5·6% by weight and, therefore, in its absence chlorophyll is not formed, and the plant becomes stunted in growth. It is present to a considerable extent in the seeds of cereals and leguminous plants.

3. **Calcium.** It is always present in green plants. It occurs in the cell-wall, particularly in the middle lamella, as calcium pectate. It is useful in neutralizing acids which otherwise would create toxic effect on plants. It helps to maintain the semi-permeability of the protoplasm. It is also anti-toxic to various poisonous substances. It also promotes the growth of roots. Plants like lemon, orange, shaddock, etc., grow well in a soil rich in calcium (lime). Fruits in general, and stone-fruits in particular, require plenty of calcium (lime) for their normal development. The stone of the stone-fruit very often does not form in the absence of lime in the soil. In general plants become stunted in growth in the absence of calcium. Many plants, however, cannot stand a high amount of calcium in the soil, and they become chlorotic in consequence.

4. **Iron.** It is essential for the formation of chlorophyll although it is not present as a constituent. It may be asso-

ciated with the plastids. Iron is always present in the protoplasm and in the chromatin of the nucleus.

5. **Sodium.** It is present in almost all soils as sodium chloride or common salt. It is absorbed to a greater or less extent by all plants although it does not take any part in the vital functions. In fact, in higher percentage it is deleterious to the life of the plant. It can partly replace potassium, but no plant will survive in the total absence of potassium.

6-7. **Sulphur and Phosphorus.** Sulphur is a constituent of an amino-acid, cystine, which is one of the compounds forming plant protein. It is an important constituent of mustard oil. It is contained in the living substance, viz. the protoplasm. In its absence leaves become chlorotic and the stem slender. Phosphorus is always present in the nucleoprotein, a constituent of nucleus, and in lecithin, a constituent of protoplasm; it promotes nuclear and cell-divisions, and is concerned in carbohydrate breakdown in respiration. Phosphorus aids in nutrition and hastens maturity and ripening of fruits, particularly of grains. It promotes the development of the root system. Underground organs like radish, beet and potato require phosphorus for their normal development. Sulphur is absorbed as sulphates of some metals and phosphorus as phosphate of calcium or potassium.

8. **Chlorine.** It is absorbed as chlorides of some metals, particularly of sodium. It does not play any important part in plant life. Chlorides are readily soluble in water, and hence various metals are absorbed from the soil in this form.

9. **Silica or Sand.** It is absorbed in the form of silicates of sodium, and is finally deposited as crystals on the surfaces or in surface-layers of leaves and stems, as in grasses and *Equisetum*.

10. **Oxygen.** As free oxygen it is absorbed from the air, and is indispensable for respiration of all the living cells of the plant. It is also absorbed from the soil in inorganic compounds. It is also present in many organic products, but as the gas oxygen it is most important for respiration.

11. **Hydrogen.** As free hydrogen it has no use. Combined with oxygen it forms water, and is absorbed as such. It forms a component part of organic and many inorganic compounds.

12. **Carbon.** It forms the main bulk—45% or even more—of the dry weight of the plant. It is the predominant constituent of all organic compounds which are, in fact, known

as compounds of carbon. Carbon is absorbed from the atmosphere as carbon dioxide. Although carbon dioxide occurs in the air to the extent of only 0·03%, still air is the only source of all the carbon for the plant, as proved by water culture experiments. It is to be noted that there is a regular circulation of carbon dioxide and oxygen between the plant and the atmosphere, and two processes are connected with it: one is photosynthesis and the other is respiration. In photosynthesis *green* plants take in carbon dioxide from the atmosphere *during the daytime* and give off oxygen. There is thus a tendency of the atmosphere becoming poorer in carbon dioxide and richer in oxygen. In the reverse process, i.e. in respiration, *all* plants and animals take in oxygen from the atmosphere *at all times* and give off carbon dioxide. In the combustion of coal and wood also carbon dioxide is given out to the atmosphere. Thus the atmosphere has a tendency of becoming richer in carbon dioxide and poorer in oxygen. It is evident, therefore, that the total volumes of these gases remain constant in the air.

13. **Nitrogen.** Although nitrogen occurs to the extent of about 78 parts in every 100 parts of air by volume, it is not as a rule utilized by plants in its free state. It may enter the plant body through the stomata with other gases, but it comes back unused. Although nitrogen is so abundant in the air, it occurs in the dry substance of the plant to the extent of 1-3% only. Nevertheless, it is indispensable to the life of the plant, as it is an essential constituent of proteins, chlorophyll and protoplasm. Nitrogen is essential for growth, more particularly of the leaves. Leafy herbs like lettuce suffer considerably in the absence of nitrogen in the soil. In the absence of this element leaves become yellowish. An excess of nitrogen causes vigorous growth of vegetative parts, specially the leaves, but delays reproductive activity. Plants become readily susceptible to the attacks of fungi and insects in the excess of nitrogen.

Nitrogen of the Soil. The amount of nitrogen in the soil varies from 0·096 to 0·21% (average Indian soil contains about 0·05% of nitrogen); still soil is the main source of nitrogen for the plant. Here it exists as *inorganic* and *organic* compounds. The chief forms of inorganic compounds are the nitrates and nitrites of potassium and calcium, and also ammonia and its compounds; while the organic compounds are chiefly the proteins. Normally the ammonium compounds present in the soil are made available for the use of the green plants after conversion into nitrate by the action of certain micro-organisms

—the nitrifying bacteria—which live in the soil. The process is called **nitrification.** In this process the ammonium compounds are oxidized into nitrate in two stages: (*a*) these are acted on by the nitrite-bacteria (*Nitrosomonas*) and oxidized into nitrite (-NO_2), and (*b*) the nitrite thus formed is again acted on by the nitrate-bacteria (*Nitrobacter*) and further oxidized into nitrate (-NO_3). The nitrate, thus produced, is readily absorbed by green plants. In certain types of soils, however, ammonium compounds are the chief forms in which nitrogen is readily absorbed by plants. A portion, however, of the ammonium compounds is disintegrated by denitrifying bacteria into free nitrogen which then escapes into the atmosphere **(denitrification).**

The chief forms of organic compounds of nitrogen are the various kinds of proteins. Dead bodies of animals and plants containing proteins are decomposed by different putrefying bacteria and also to some extent by certain fungi present in the soil. In the first stage, *in the absence of oxygen*, the proteins are reduced to amino-acids and then to ammonium compounds **(ammonification)** by the putrefying bacteria and fungi; and in the second stage, *in the presence of oxygen*, the ammonium compounds undergo nitrification, as stated above. The nitrate, thus produced, is readily absorbed by green plants.

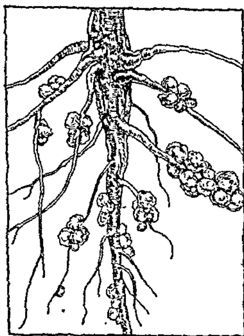
Test for Nitrates. The presence of nitrates in the plant tissue or in the soil is easily detected with diphenylamine. A 0·5% solution of it in strong sulphuric acid turns nitrates blue.

Fixation of Atmospheric Nitrogen. The gaseous nitrogen of the air combines with other elements and is ultimately made available to the plants as compounds of nitrogen in the soil. The methods by which nitrogen may be fixed are as follows: (1) discharge of electricity in the atmosphere, (2) activity of certain saprophytic bacteria, (3) activity of symbiotic bacteria, and (4) activity of blue-green algae, as established by Dr. P. K. De of State Agricultural College, Bengal:

(1) Nitro[illegible] The free nitrogen of the air to some [illegible] plants by the discharge of electricity [illegible] Under the influence of electricity ni[illegible]gen to form nitric oxide —N_2+O_2 = [illegible]de at once unites with oxygen of th[illegible] $O+O_2 = 2NO_2$ (nitrogen peroxide). The nitrogen peroxide, thus produced, is then dissolved by falling rain forming nitrous acid (HNO_2) and nitric acid (HNO_3)—$2NO_2+H_2O = HNO_2+HNO_3$, and washed down into the soil. Here they combine with some metal like potassium or calcium, and form respectively nitrite and nitrate of potassium or calcium. Nitrate is directly absorbed by plants; while nitrite is oxidized into *nitrate* by nitrate-bacteria. On an average the rain water brings down to the soil about 4 lbs. of nitrogen per year per acre

(2) Nitrogen Fixation by Saprophytic Bacteria of the Soil. *Various types of nitrogen-fixing bacteria present in the soil* have the power of fixing free nitrogen of the soil-air in their own bodies in the form of amino-acids and finally building up proteins from them. After the death of these bacteria the proteins are released to the soil. In due course these are acted on by the nitrifying bacteria and finally transformed into nitrates which are then made use of by the green plants. But it must be noted that the amount of free nitrogen fixed by the saprophytic bacteria is much less than that fixed by the symbiotic bacteria. There are two distinct groups of saprophytic bacteria—aerobic and anaerobic. Several species of *Azotobacter* (aerobic) and *Clostridium* (anaerobic) are the typical of these two groups. These bacteria are widely distributed in soils. The efficiency of nitrogen-fixation by these bacteria depends on the oxidation of carbohydrates (particularly sugars) in the soil as a source of energy. The chemistry of nitrogen *fixation is not, however, definitely known.*

(3) Nitrogen Fixation by Symbiotic Bacteria: Nodule Bacteria of *Leguminosae*. Agriculturists have noted for a long



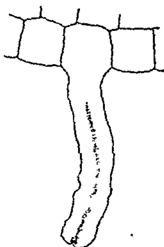


FIG. 463 FIG. 464

Fig. 463. Nodules of a leguminous plant. Fig 464. A root-hair infected with bacteria.

time that leguminous plants such as pulses grown in a soil make it fertile and lead to an increase in the yield of cereals.

It was later discovered that the roots of these plants possess some swellings, called **nodules or tubercles,** which are infected with some types of nitrogen-fixing bacteria, particularly the different strains of *Rhizobium radicicola,* and these bacteria have the power of fixing the free nitrogen of the soil-air in the said nodules. It is to be particularly noted that neither the leguminous plants nor the bacteria can fix nitrogen by themselves. It is now known that such bacteria are present in the nodules of most plants (but not all) of *Leguminosae* and in the roots of a few other plants. The mode of infection of the root by these bacteria and of nodule formation is as follows. Bacteria enter through the tip of the root-hair. After penetrating into it they form into a sort of thread consisting of innumerable bacterial cells held together by mucilage. This thread passes down the hair and reaches the cortex of the root perforating the cell-walls. Bacteria then multiply in number and colonize in the cortex. Cortical cells are stimulated to grow, perhaps due to the secretion of some stimulant by these bacteria, and thus give rise to small swellings or nodules of varying sizes and fix in them the nitrogen of the air in the form of some amino-compounds. A portion of the amino-compounds is absorbed into the plant body, another portion is excreted out of the nodules and the remaining portion remains locked up in the nodules. Thus the soil becomes richer in nitrogen, more particularly so, if the nodule-bearing leguminous plants are ploughed into the soil. The leguminous plants supply the bacteria with carbohydrates, and the bacteria supply the former with nitrogenous food; so this is a case of **symbiosis** (see p. 46). It is, however, to be noted that the initial chemical changes leading to the formation of amino-compounds in the nodules are not clearly understood.

Nitrogen Cycle. Although plants are continually absorbing salts of nitrogen from the soil it should not be supposed that the nitrogen contents of the soil would sooner or later become exhausted. Under natural conditions the soil soon becomes replenished of this element. This is so because of the fact that there is a regular circulation of nitrogen through the air, soil, and plants and animals. Nitrogen in the soil is, therefore, inexhaustible. We have already seen how the free nitrogen of the air is brought down into the soil as ultimate products of nitrite and nitrate of some metals. Nitrates are absorbed by plants and made into proteins in their body. Plant proteins are taken up by animals. After the death and decay of animals and plants the proteins contained in their body are again converted into nitrates in several stages, as already described (see p. [illegible]), and absorbed as such by plants again. At the same time a portion of the ammonium compounds present in the soil is disintegrated by denitrifying bacteria into free nitrogen or oxides of nitrogen which then escape into the air. This free nitrogen is again brought down into the soil from the [illegible]

Rotation of Crops. The fixation of atmospheric nitrogen in the soil is of very great agricultural importance. Most crops absorb the nitrogenous

compounds from the soil and impoverish it. Leguminous plants, on the other hand, enrich it in nitrogen when their nodule-bearing roots are left in the soil Thus leguminous crops such as pulses, *Sesbania cannabina* (B. DHAINCHA), cow pea (*Vigna sinensis*), etc., are grown in the field in rotation with the non-leguminous crops such as cereals (rice, wheat, maize, barley, oats, etc.) and millets. Root crops such as turnip, radish, beet, etc., take plenty of potash, calcium and nitrogen from the soil.

Trace- or Micro-elements. It is now definitely known that at least five 'trace' elements such as boron, manganese, zinc, copper and molybdenum are essential for normal growth of plants. The absence of any of them in the culture solution or in the soil leads to abnormal growth and to certain plant diseases. It may also be mentioned that aluminium though not recognized as essential is very widely distributed among plants. The normal culture solution, however, does not include any of the 'trace' elements, and still the plant grows. How to explain it? It is likely that some of the so-called pure chemicals used by the early workers contained traces of these elements. Distilled water commonly used in the water culture experiments might have contained traces of them. Traces of some of these elements might have dissolved out of the glass bottles and other vessels containing the chemicals and the solutions. Besides, seeds themselves are likely to contain these elements in their cotyledons or endosperm. Thus the sources of contamination of the water culture solution being many, such elements crept into the solution undetected. In recent times by using extra-pure chemicals, re-re-distilled water and special glass bottles it has been proved beyond doubt that the five elements, mentioned above, are indispensable and essential for all green plants

Boron. It is possibly required by all plants. The beneficial effect of boron has been proved in a number of cases, e g. tomato, tobacco, lemon, beet, turnip, mustard, cotton, etc. Cauliflower is in particular need of boron, while cereals have a very low requirement for it. Boron helps the formation of root-nodules in leguminous plants, and it improves the yield of sugar in beet. In its absence beet suffers from 'heart rot', tobacco from 'top rot', potato from 'leaf roll'. In general, in its absence the growth of the plant is retarded and the leaves become spotted Its absence particularly affects the apical meristems, i.e. the root-tip and the stem-tip, which become brittle and die off.

Manganese. Absence of this element or its deficiency results in drying up of leaves, weak growth of the plant, poor bloom, chlorosis and certain diseased conditions of leaves. There is always an appreciable amount of manganese in orange, lemon and tomato, and it is likely in them there is a relationship between manganese and vitamins. Cabbages require manganese while, as stated above, cauliflower is in need of boron. In pines and allied plants there is comparatively a high percentage of manganese. This element particularly benefits the leguminous plants.

Zinc. Absence of zinc results in stunted growth of the leaf and the shoot, mottling of leaves, drying back of the growing tips and also various physiological diseases. Cells of leaves also do not utilize carbohydrates in respiration in the absence of zinc. The beneficial effect of zinc has been already proved in a number of cases, e.g., cereals, lettuce, pea, bean, lupin, beet, potato, kohl-rabi, tomato, and many fruit trees. Zinc occurs more abundantly in chlorophyll bearing tissues than in other parts and helps the formation of chloroplasts, as proved by Reed in 1935.

hlorophyll-formation.
in the root medium.
ed in flax, tomato,
formation of starch

Molybdenum. Molybdenum is known to be essential for plant growth. The first sign of the deficiency of this element is the formation of chlorotic or necrotic areas in the leaf. It has been claimed that this element is

required in the cells for the reduction of nitrate to ammonia for protein synthesis. On this basis it is considered to enter into the composition of enzymes. There is also evidence that this element is required for nitrogen-fixation by *Azotobacter* and *Rhizobium*.

Aluminium. Aluminium has been found in the ash of many plants in a very small percentage, specially in wheat, maize, rye, bean, lentil, carrot, cabbage, turnip, lettuce, sunflower, etc. It is, however, found in a large quantity in the ash of *Lycopodium*. Aluminium is found in almost all parts of the plant body, more so in the root and the leaf. It occurs mainly in the protoplasm and the nucleus. Aluminium in very low concentration stimulates growth, while in higher concentration it is toxic. It influences the colour of the flower.

CHAPTER IV

ABSORPTION OF WATER AND RAW FOOD MATERIALS

Roots and leaves are the main absorbing organs of plants. Roots absorb water and dissolved mineral salts from the soil and leaves take in gases—oxygen and carbon dioxide—from the atmosphere.

I. Water and Inorganic Salts from the Soil. Green plant absorbs water and inorganic salts from the soil by the unicellular root-hairs which pass irregularly through the interstices of the soil particles and come in close contact with them. Absorption is also actively carried on by the growing regions of the roots. Water is absorbed in large quantities, always in excess of the requirements of the plant. Simultaneously small quantities of various soluble inorganic salts such as nitrates, chlorides, sulphates, phosphates, etc., dissolved in the soil-water are absorbed in a state of *very dilute solution*. Many of these salts are readily soluble in the thin film of water that surrounds each soil particle. Some are insoluble in pure water but may be rendered soluble by a small quantity of acids, chiefly acid potassium phosphate and carbonic acid, secreted by the roots. That this is so is evident from the fact that a piece of marble, remaining in contact with the roots for some time, becomes etched to a certain depth.

Availability of Soil Water. A portion of the water moves downward in response to the force of gravity, rapidly through sandy soil and slowly through loam or clay soil, and carries down or sometimes even washes out a considerable quantity of essential food elements. This moving water percolates through the soil particles and is not of any use to the plant as root-hairs cannot absorb it. Then again each soil particle holds some water within it by the force of imbibition (see p. 291);

this water is known as *hygroscopic water*. It is held so tenaciously by the soil particle that the root-hairs cannot dissociate it from the particle. This hygroscopic water also is not of any use to the plant. Surrounding each soil particle there is a thin or sometimes thick film of water, loosely held by it by capillary force; this is known as *capillary water*. It also occurs in the spaces between the soil particles. This capillary water together with the various nutrient salts dissolved in it can be readily absorbed by the root-hairs and is, therefore, regarded as the principal source of supply of water to the plant. Capillary water may move from particle to particle in any direction. If this capillary water diminishes in quantity the plant suffers and even death may occur due to wilting. It must, however, be noted that capillarity cannot raise water for more than a few feet from the deeper water level of the soil, except near tanks, lakes and rivers; capillarity still remains useful in the cases of deep-rooted plants.

II. Gases from the Atmosphere. Of the various gases present in the air[1] it is only the oxygen and the carbon dioxide that are absorbed and utilized by the plant. Other gases may enter the plant body, but they are returned unused. Oxygen is absorbed and utilized by all the living cells of the plant for respiration; but carbon dioxide is absorbed by only the green cells for the manufacture of carbohydrates.

Imbibition. Imbibition is the phenomenon of soaking up water by certain materials, particularly in dry or semi-dry condition. Fibres, pieces of wood, some proteins, sponges, etc., are some such materials. The cell-wall and the prtoplasm are also able to absorb water by imbibition, and it plays an important role in the physiology of plant life. Imbibition can only occur when there is an affinity between the two. Thus cotton fibres imbibe water, while rubber does not. In this process the constituent particles of a particular substance take up water by *surface attraction* and increase in volume. For this reason seeds soaked in water are seen to swell up. The amount of attraction of dry cell-walls and of protoplasm for water is often very great and a considerable imbibitional force may be developed within the plant body. As a result of imbibitional pressure the seed-coat of a germinating seed bursts. Germinating seeds kept in a closed vessel often burst it with tremendous pressure. Imbibition is believed to be an important force

[1] **Composition of the Air.** Of 100 parts of air by volume nitrogen occupies 78%, oxygen 21%, carbon dioxide 0·03%, and other gases such as hydrogen, ammonia, ozone, aqueous vapour, etc., occur in traces only.

concerned in the ascent of sap (see p. 307). Imbibition also plays an important part (together with osmosis, as explained at p. 294) in the intake of soil-water by the root-hairs. In an imbibing system it is the rule that the water always moves with some force from a saturated region to a drier region.

Osmosis. It has been observed that there are certain membranes which when used to separate a solvent (water, for example, which is the only important solvent in plants) and a solute (salt or sugar in water) allow the solvent on the one side to pass through them freely but at the same time resist the solute on the other side so that only a minute quantity of the latter can cross through. On account of this property of selective transmission such membranes are said to be semi-permeable or differentially permeable. Parchment paper, fish- or animal-bladder and egg-membrane are some such membranes. So far as the plant cells are concerned the ectoplasm (and not the cell-wall) acts as the differentially permeable membrane. When weak and strong solutions are separated by such a membrane there is a net transfer of the solvent from the weaker solution to the stronger one. *This process of selective transmission of a liquid in preference to another or a solvent in preference to the solute through a semi-permeable membrane is termed* **osmosis.** By this process of osmosis one liquid passes on to the side of the other liquid or the solvent passes from the side of the weaker to that of the stronger solution and goes on accumulating there. This process continues until the *hydrostatic* pressure due to the accumulated flow of the liquid or solvent has attained a value sufficient to stop further flow. This excess pressure which is just sufficient to stop the flow through the membrane is called the **osmotic pressure** of the stronger solution. It has been found that this pressure is proportional to the concentration of the solution, or, in other words, the greater the concentration of a solution the greater would be the osmotic pressure of it (the solution). A familiar example of osmosis is this: raisins immersed in water are seen to swell up as a result of endosmosis, and at the same time a small quantity of the high percentage of sugar contained in them is found in the water outside as a result of exosmosis. Similarly, grapes immersed in strong solution of sugar or salt (say, 25% or 30%) are seen to shrink.

Experiment 2. Physical process of osmosis (fig. 465). Take a wide thistle-funnel with a narrow long stem and close its mouth with parchment paper or fish-bladder. Fill it with strong salt solution a little above its neck and introduce it, stem upwards, into a beaker containing water. Mark the level of the solution in the stem. After a few hours note that the level of the solution in the stem has gone up. This rise is due to the accumula-

tion of water in the funnel as a result of more rapid flow of the water into the thistle-funnel by osmosis (endosmosis) through the membrane. This rise is seen to continue until the level has gone sufficiently high up to exert a hydrostatic pressure on the membrane which then stops further net transfer of water by osmosis. This value of the hydrostatic pressure is equal to the osmotic pressure of the solution. At the same time a small quantity of salt also passes out through the membrane.

Experiment 3. Physiological process of osmosis (figs. 466-7). (a) Take a large potato tuber. Remove the skin from it and slice off the bottom to make it flat. Scoop out the central flesh with a knife or scalpel into a deep hollow cavity with the wall comparatively thin. Place it in a small beaker and pour some strong salt or sugar solution into it so as to cover more or less three-fourths of the cavity. Then pour water into the beaker almost to its brim. The water may be coloured with a few drops of eosin. Within a short time the solution in the cavity is seen to increase in volume turning reddish and to overflow it soon after as a result of endosmosis. The presence of a small quantity of salt or sugar may also be detected in the water of the beaker as a result of exosmosis.

(b) The experiment may be carried out in a modified form with a **potato osmometer** (fig. 467). The potato tuber, after skinning the sides and slicing off the bottom, may be scooped out into a deep hollow cavity and salt or sugar solution poured into it. A soft cork of appropriate size with a glass tube fitted in it may then be gently but tightly pressed in.

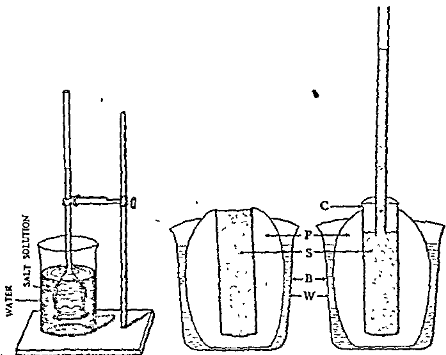


FIG. 465 FIG. 466 FIG. 467

Experiments of Osmosis. Fig. 465. Physical process of osmosis. Fig. 466. Physiological process of osmosis. Fig. 467. The same with potato osmometer. *C*, cork; *P*, potato tuber; *S*, sugar solution; *B*, beaker; *W*, water.

Place the potato tuber in a beaker and fill it (the beaker) with water. Within a short time the salt or sugar solution is seen to rise in the glass tube, soon overflowing it. The actual rise is a few to several feet, depending on a number of factors.

Soil and Root. The repeated branching of the root, its ramifications in all directions and penetration downward, coupled with the production of root-hairs in enormous numbers help the plant to absorb a huge quantity of water, etc., from the soil. It has been estimated that the total length of the root system of a plant may be several miles, and in some cases a few hundred miles. Millions or even billions of root-hairs, each coming in intimate contact with many soil particles, may be formed by a single plant, thus enormously increasing the absorbing area of the root. The plant has thus developed an elaborate system for the intake of water and mineral salts from the soil It is the root-hairs and the tender growing regions of the roots that are utilized by plants for the purpose of absorption , the older parts of the roots, being impervious to water, are of no use in this respect.

Parts played by Root-hairs (fig. 468). In the case of root-hairs which contain some sugars and salts in solution, the cell-sap is stronger than the surrounding soil-water. The two fluids (cell-sap and water) are separated by the cell-membrane (cellulose cell-wall + plasma membrane). As a consequence osmosis is set up There is a flow of water from the soil into the root-hairs through the intervening cell-membrane (endosmosis) Osmosis, however, is not in this case a purely physical process. Although the cell-wall is permeable to both the water and the solutes, the plasma membrane is but differentially and selectively permeable, allowing the water to flow in, while checking the sugars and salts of the cell-sap to flow out. This selective permeability is characteristic of the plasma membrane. It is also to be noted that the same membrane varies in its permeability under different conditions.

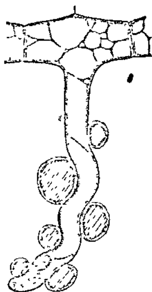


FIG. 468 A root hair with soil particles adhering to it

The absorption of water by the root-hairs is not, however, so simple a process as depicted above A number of factors such as concentration of solution, supply of oxygen to the root, temperature of the soil, nature of salts present, etc , are concerned in the process. It is also believed by many authors that root-hairs normally absorb the soil water by imbibition (see p. 291), osmosis being a minor factor. It is, however, likely both the processes, viz. osmosis and imbibition, are operative in the intake of water by the root-hairs. Diffusion is also believed by some authors to be an important factor in this respect

Turgidity. As a cell absorbs more and more water resulting in its accumulation in the vacuole, a certain pressure is exerted on the surrounding protoplasm and the cell-wall. As a consequence the protoplasm is forced outward against the cell-wall and the latter also becomes much stretched. The stretched cellulose wall being elastic tends to return to its original shape and thus in its turn exerts a pressure upon the fluid contents of the cell. *A cell thus charged with water with its wall in a state of tension is said to be turgid, and the condition is designated as* **turgidity.** It will be noted that under turgid condition of a cell two pressures are involved: outward and inward. The outward pressure exerted on the cell-wall by the fluid contents of the cell is called the **turgor pressure,** and the inward pressure exerted on the cell-contents by the stretched cell-wall is called the **wall pressure.** Normally these two pressures counterbalance each other and a state of equilibrium is maintained between them.

Three factors influence the turgidity of a living cell, viz. (1) formation of osmotically active substances inside the cell, (2) an adequate supply of water, and (3) a semi-permeable membrane.

Importance. Turgid condition is necessary for the transit of nutrient solution from cell to cell; this is so because of the difference in the concentration of the cell-sap between one cell and the other. *Turgidity is also necessary for growth; in fact,* it is always the initial stage of growth. Rapid growth of certain organs of plants is principally due to turgidity, i.e. full expansion of the cells of those organs, and not to their rapid *multiplication. Turgidity is also responsible for various movements* of different organs of the plant. Thus movements of the guard-cells of the stomata are due to changes in the turgidity of these cells, and similarly, the rising and the falling of the leaf and the leaflets of sensitive plant (see fig. 505), Indian telegraph plant (see fig. 499), etc., are brought about by alterations in the turgidity of the cells of the pulvinus. Turgidity of the cells of the root-cortex is responsible for forcing the water into the xylem vessels. Turgidity also gives a certain amount of rigidity to the plant, particularly to the growing regions and the soft leaves which easily wilt in strong sunlight, and also to other soft parts composed of only thin-walled parenchyma without any mechanical tissue.

Plasmolysis (fig. 469). If a section from a green leaf, or a coloured petal, or a *Spirogyra* filament be placed in strong *salt or sugar solution (say, 5 or 10 per cent solution)*

observed under the microscope, it will be seen that the cell as a whole contracts and more obviously the protoplasm together with the nucleus and the plastids gradually shrinks away from the cell-wall and forms a rounded or irregular mass in the centre; while the space between the cell-wall and the protoplasmic mass becomes filled with the salt or sugar solution. The reason for such shrinkage of the protoplasm is that the salt or sugar solution being of greater osmotic value than the cell-sap, the cell loses water by outward osmosis. As the water moves out of the cell, the protoplasm and the cell-wall are no longer in a state of tension. Further loss of water evidently results in the shrinkage of the protoplasm. *This shrinkage of the protoplasm from the cell-wall under the action of some strong solution—stronger than that of the cell-sap—is known as* plasmolysis. If the salt or sugar solution be replaced by pure water, soon after plasmolysis, the protoplasm is seen to return to its normal position and the vacuole reappears (deplasmolysis). Potassium nitrate solution (10%) is a very good reagent to bring about plasmolysis.

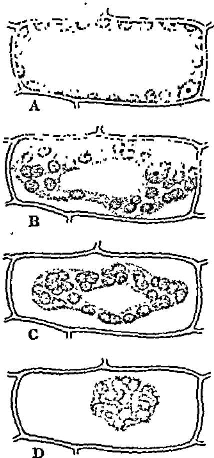


FIG. 463. Plasmolysis in a cell of *Vallisneria* leaf under the action of 10% potassium nitrate solution; *A*, a normal cell; *B-D*, stages in plasmolysis.

Plasmolysis is a vital phenomenon. It explains on the one hand the phenomenon of osmosis, and on the other it shows the permeability of the cell-wall and semi-permeability of the outer layer of the protoplasm—the ectoplasm—to the entrance of certain substances. Plasmolysis also shows that the protoplasm can retain the osmotically active substances of the sap. This is evident from the fact that the plasmolyzed protoplasm turns back to its original position when the salt solution is replaced by pure water. The phenomenon of plasmolysis also indicates whether the cells are

living or dead. When the cells are killed by gently boiling for *a few seconds, they show no plasmolysis. From plasmolysis* it is also possible to determine the osmotic pressure of a cell.

CHAPTER V

CONDUCTION OF WATER AND RAW FOOD MATERIALS

ROOT-PRESSURE

The water that is absorbed from the soil by the root-hairs, whether by the process of osmosis or imbibition, gradually accumulates in the tissue of the cortex. As a result of this accumulation of water the cells of the cortex become fully *turgid. Under this condition their walls which are composed* of cellulose exert pressure on the fluid contents and force out a quantity of them towards the xylem vessels, and the cortical cells become *flaccid*. They again absorb water and become

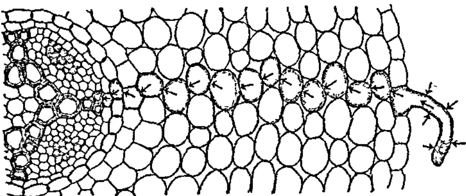


FIG. 470. A root in transection showing the course of water from the root-hair to the xylem.

turgid and the process continues. Thus an intermittent pumping action goes on in the cortex of the root, and this pumping action naturally gives rise to a considerable pressure. As a result of this pressure the water is forced into the xylem vessels through the passage cells and the unthickened areas and pits that the endodermis and the vessels are provided with. Besides, the lignified walls of the vessels are also permeable by water. **Root-pressure** *is thus explained as the pressure exerted by the cortical cells of the root upon their liquid contents under fully turgid condition forcing a quantity of them into the xylem vessels and through them upwards into the stem.*

Experiment 4. Root pressure (fig. 471). Cut across the stem of a healthy plant (preferably a pot plant) a few inches above the ground in the morning, and fix to it, by means of a rubber tubing, a T-tube. Pour some water into the tube and freely water the soil. Fill a manometer (i.e. the U-tube with a long arm and a bulb) partially with mercury, as shown in the figure. Connect the manometer to the T-tube through a rubber cork. Insert a cork fitted with a narrow glass tube to the upper end of the T-tube. Make all the connexions air-tight by applying melted paraffin-wax. Seal the bore of the narrow tube and note the level of mercury in the long arm of the manometer.

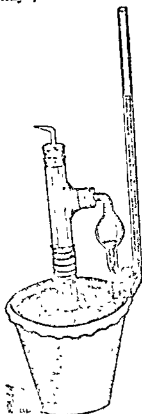


Fig. 471. Experiment on root-pressure

Observation. After a few hours note the rise of mercury-level in the long arm; also note the rise of water level in the T-tube.

Inference. The rise of mercury is certainly due to accumulation of water in the T-tube and the pressure exerted by it. This phenomenon is evidently due to exudation of water from the cut surface of the stem. This experiment thus shows that the water is *forced up* through the stem by root pressure.

Root-pressure is continually forcing up the water through the xylem (or wood), but it is difficult to determine the process when active transpiration is in progress. The water accumulates in the vessels only when transpiration is in abeyance. Sometimes it so happens that certain plants, when cut, pruned, tapped or otherwise wounded, show a flow of sap from the cut ends or surfaces, not unoften with considerable force. This phenomenon is commonly known as *bleeding*, and is often seen in many land plants in the spring, particularly grape vine, some palms, sugar maple, etc. Although the flow of sap is ordinarily slow, a considerable quantity of it exudes within a period of 24 hours in certain plants. Thus in some palms, when tapped, there may be a flow of sap to the extent of 10-15 litres per day. The sap in such plants contains sugar in addition to organic and inorganic salts.

Conditions affecting Root-pressure

1. **Temperature.** Temperature of the air as well as of the soil affects root-pressure. The warmer the air and the soil the greater is the activity of the root.

2. **Oxygen.** There must be an adequate supply of oxygen to the roots in the soil for respiration; otherwise their activity diminishes and may soon come to a standstill.

3. **Moisture in the soil.** A certain amount of moisture must be present in the soil. Within certain limits, the more the better.

4. **Salt in the soil.** Preponderance of salts, making the soil saline, greatly interferes with the absorption of water.

TRANSPIRATION

Plants absorb a large quantity of water from the soil by the root-hairs. Only a part of this water is retained in the plant body for the building up processes, while a greater part of it is lost in the form of water vapour. **Transpiration** *is the giving off of water vapour from the internal tissues of living plants through the aerial parts such as the leaves, green shoot, etc., under the influence of sunlight, regulated to some extent by the protoplasm.* It is not a simple process of evaporation since it is regulated by the vital activity of the protoplasm and some structural peculiarities of the transpiring organs (see p 304). A detached leaf is seen to lose water much more rapidly than the one still attached to the plant, and this loss has been found to be 5 or 6 times greater The total quantity of water that evaporates from a single plant is considerable. It has been estimated that the loss of water from a single sunflower plant during a period of 144 days is 27,000 c.c. This means there is a daily average loss of 187·5 c c. The mechanism of transpiration is this. Water evaporates at all temperatures, and since the parenchymatous cells are charged with water, it continues to evaporate from these cells and collect in the intercellular spaces so long as these are not saturated with water vapour. From there the water vapour escapes into the atmosphere either through the stomata or through the thin cuticle. The former is called **stomatal transpiration,** and the latter **cuticular transpiration.** The stomatal transpiration is the rule, and is many times in excess of the cuticular transpiration. At night stomata remaining closed transpiration is checked. Since water vapour is given off in transpiration, the process markedly affects the humidity of the air around. The air under big leafy trees is moist and cool for the same reason. In dorsiventral leaves the lower surface has always a larger number of stomata ; often none are present in the upper. Consequently this surface transpires water more vigorously than the upper. In isobilateral leaves, however, stomata are more or less evenly distributed on both the surfaces. The guard-cells regulate transpiration by partially or completely opening the stoma or by closing it altogether.

according to circumstances. Lenticels (see fig. 455) are also concerned in the process of transpiration; water vapour escapes through the loose mass of cells of the lenticel.

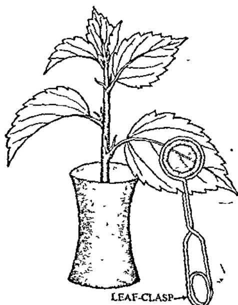


FIG. 472. Experiment on unequal transpiration.

Experiment 5. Transpiration: bell-jar experiment. Transpiration can be easily demonstrated in the following way. A pot with its soil-surface covered properly with a sheet of oil paper is enclosed in a bell-jar and maintained at room temperature for some time. It is then seen that the inner wall of the bell-jar becomes bedewed with moisture.

Experiment 6. Unequal transpiration from the two surfaces of a dorsiventral leaf (fig. 472). Soak small pieces of filter paper or thin blotting paper in 5% solution of cobalt chloride (or cobalt nitrate) and dry them over a flame. The property of cobalt papers is that they are deep blue when dried, but in contact with moisture they turn pink. Place two dried cobalt papers, one on the upper and the other on the lower surface of a thick, healthy leaf, as shown in the figure. Cover them completely with mica pieces or glass slides (or with a leaf-clasp, as shown in the figure), and clamp them properly to the leaf. Then quickly seal the sides with vaseline to prevent atmospheric connexion.

Observation. It will be seen in our experiment that the cobalt paper on the lower surface of the leaf turns pink sooner than the one on the upper surface. This change in colouration takes place within a few minutes.

Inference. This evidently shows that the leaf transpires water more vigorously from the lower surface than from the upper. This, as already explained before, is due to the occurrence of a large number of stomata on the lower surface, none or few being present on the upper.

Experiment 7. Measurement of the rate of transpiration current (fig. 473). This experiment is best carried on with the help of a potometer, as depicted in the figure. The apparatus is filled with water, and a branch cut under water is fixed air-tight to the upper wide end of the apparatus through a cork. The distal end of the apparatus is dipped into water contained in a beaker. The water of the beaker may be coloured with eosin. As transpiration goes on, the coloured water is seen to enter the tube. Then remove the end of the tube from the beaker for a while and allow air to enter it. Dip it into water again. An air-bubble is seen to be formed at the distal end of the tube; it rises and slowly travels through the horizontal arm of the potometer as a result of suction due to transpiration. Note the time that the bubble takes to cover the journey from one end of the graduation to the other. The volume of the graduated tube being known (or separately worked out), the rate of transpiration current is easily determined. By opening the stopcock the bubble may be pushed back and the experiment re-started.

Experiment 8. Relation between transpiration and absorption (fig. 474). A wide-mouthed bottle with a graduated side-tube and a split India rubber cork are required for this experiment. A small rooted plant is introduced

through the split cork into the bottle which is filled with water. The level of water is noted in the side-tube, and 1 or 2 drops of oil poured into it

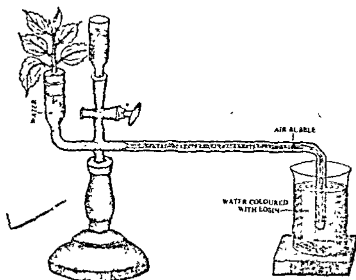


Fig. 473. Experiment showing the rate of transpiration current.

to prevent evaporation of water from the exposed surface. The connexions are, of course, made air-tight. The whole apparatus is then weighed on a compression balance (fig. 475) and the weight noted. It is seen after a time that the water-level has fallen, indicating the volume of water that has already been absorbed by the plant. The apparatus is then re-weighed. The

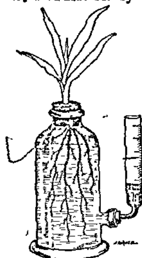


Fig. 474. Relation between transpiration and absorption.

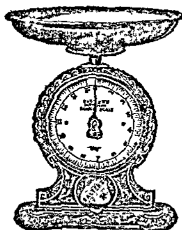


Fig. 475. Compression balance.

difference in weight evidently shows the amount of water that has transpired from the leaf-surfaces. If the experiment be continued for a period of 24 hours it will be seen that the volume of water (in c.c.) absorbed is slightly greater than the amount of water (in grams) lost by transpiration

(1 c.c. of water=1 gm of it). In this way the relation between transpiration and absorption can be worked out for the various hours of the day and under diverse external conditions (see factors which affect transpiration, p. 303).

Note This experiment not only shows the relation between the two processes—transpiration and absorption—but also separately proves 'absorption' and 'loss of water' by transpiration.

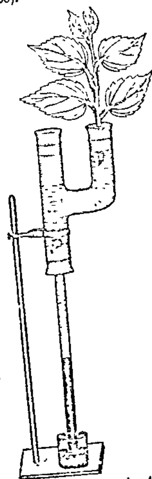


Fig. 476. Suction due to transpiration.

Experiment 9. Suction due to transpiration (fig. 476). Take a manometer (i.e. the tube with a side arm, as shown in the figure) and fix to its lower end a long narrow glass tube. Completely fill the tubes with water and insert a leafy shoot, with the cut end kept under water, into one of the arms of the manometer through a rubber cork. Close the other end with a cork. Make all the connexions air-tight by applying melted paraffin wax. Dip the lower end of the tube into mercury in a beaker. As transpiration goes on water is absorbed, and within a few hours mercury is seen to rise in the tube to some height. This rise of mercury indicates the suction exerted by transpiration. The physiological processes connected with this phenomenon are (*a*) osmosis in the mesophyll cells by which water is withdrawn from the tracheids in the veinlets; (*b*) evaporation of water from the mesophyll cells through the leaf-surface, bringing about concentration of their cell sap; and (*c*) transpiration pull exerted on the column of water in the long tube, resulting in its absorption into the branch and the rise of mercury in consequence.

Transpiration Coefficient. The quantity of water lost by transpiration is very great as compared with that used by plants in the manufacture of dry matter in them. The difference in the quantity of water absorbed and that lost by transpiration is utilized in the manufacture of dry matter (food and other organic compounds). Transpiration coefficient, also expressed as the water requirement of the plant, represents the number of grams of water absorbed to produce one gram of dry matter. Transpiration coefficient varies from plant to plant and also in the same plant under different conditions. The values already worked out for some of the field crops under certain conditions are 350 for maize or Indian corn, 500 for wheat, 636 for potato and 900 for lucerne or alfalfa (a fodder crop). The values in terms of transpiration coefficient mean that 350, 500, 636 and 900 grams of water have been absorbed by maize, wheat, potato and lucerne respectively to produce one gram of dry matter in each case.

Importance of Transpiration. Transpiration is of vital importance to the plant in many ways. (1) In the first place we find that roots are continually absorbing water from the soil, and this water is several times in excess of the immediate requirement of the plant; the excess is got rid of by transpiration. (2) There is a definite relation between transpiration and absorption.

absorption. The greater the transpiration the greater is the rate of absorption of water from the soil. (3) Absorption of water helps the intake of raw food materials (inorganic salts) from the soil. It is, however, not a fact that the greater the transpiration the greater is the rate of absorption of inorganic salts from the soil. As a matter of fact the intake of salts is independent of the quantity of water absorbed. (4) Transpiration secures concentration of the cell-sap and thereby helps osmosis. (5) As a result of transpiration from the leaf-surface a suction force (see experiment 9) is generated which helps in the ascent of water to the top of lofty trees. (6) Transpiration also helps the distribution of water throughout the plant body. (7) As a result of transpiration, plants become cool as a considerable amount of latent heat is lost in converting water from liquid to gaseous state. (8) Lastly, transpiration has some ecological significance in some plants. As the water evaporates the hygroscopic salts are left on the surface of the leaf. These salts absorb moisture from the atmosphere, and do not allow the leaf or the plant as a whole to dry up. In the face of all these advantages the fact cannot be overlooked that excessive transpiration is often a real danger to plant life. Many plants are often seen to dry up and die when excessive transpiration takes place for a prolonged period.

Factors which affect Transpiration

1. **Light.** Light is the most important factor. Transpiration in light is much greater than in darkness. This is due to the fact that during the daytime stomata remain fully open and evaporation of water takes place normally through them. At night stomata remain closed and consequently transpiration is markedly checked. During the daytime again heat-rays of the sun directly falling upon the leaves enhance to a great extent the rate of transpiration.

2. **Humidity of the Air.** There is an increase or decrease in the rate of transpiration according as the air is dry or moist. When the atmosphere is very dry it receives moisture very readily, but when it becomes very moist or saturated it can receive no more water vapour. Loss of water by transpiration is then very slight.

3. **Temperature of the Air.** The higher the temperature, the greater is the transpiration ; at high temperatures the water evaporates more freely than at low temperatures. When the two factors, viz. dryness of the air and high temperature, combine transpiration is markedly enhanced.

4. **Wind.** During high wind transpiration becomes very active because the water vapour is instantly removed and the area around the transpiring surface is not allowed to become saturated.

Adaptations to reduce excessive Transpiration. *Anatomical.* Thick cuticle and sometimes multiple epidermis develop to check excessive evaporation of water. The loss of water from an apple with the cuticle removed is far greater than that from the one with the cuticle intact. The presence of cutinized hairs, scales, rods, etc., minimizes transpiration to a great extent. A dense coating of hairs or of wax or 'bloom' on the surface is very efficient in this respect. Latex also checks transpiration. Stomata may be closed temporarily even at day-time when excessive transpiration is taking place from the leaf-surface. In desert plants stomata remain sunken in pits (see figs. 427-8), and these (stomata) are also very much reduced in number. After a time in shrubs and trees cork is formed to act as a waterproof covering and to afford protection of other kinds (see p. 271). Cork cells being suberized are impervious to water and, therefore, loss of water by transpiration is prevented. A peeled potato transpires more quickly than an unpeeled one. Later still in the life of these plants bark is formed as a hard, dry covering to carry on identical functions.

Morphological. The leaf-area is often very much reduced; in extreme cases leaves are modified into spines. The size of the plant is also often reduced. Leaves may be rolled up or variously folded exposing minimum surface for evaporation. They may also assume a drooping or vertical position to avoid strong sunlight. It is further seen that deciduous trees shed their leaves in winter as a protection against excessive evaporation, while evergreen trees have their leaves well covered with cuticle.

Exudation of Water. The excess of water is also got rid of in many herbaceous plants by a process, commonly called '*exudation*', or '*guttation*'. Thus in water lettuce, grape vine, many aroids (e.g. taro), garden nasturtium, many grasses, etc. it is seen that drops of water accumulate at the apex or margin of the leaf in the early morning. The water has escaped through the water stomata (or water pores) and hydathodes that have developed in that region (see p. 223). That the water is not dew-drops is evident from the fact that the drops are regularly arranged at the ends of [illegible] and that the chemical analysis shows the presence of [illegible] and inorganic salts.

Exudation normally takes place during a warm and damp night. In some plants a considerable quantity of water exudes every night. The cause of exudation is to be sought in the wall-pressure (see p. 295) that develops in the fully turgid parenchymatous cells that lie in the adjoining parts. Conditions necessary for the process are: abundant supply of water, a suitable temperature and activity of the living cells of the root; and also other conditions which check transpiration. At very low temperatures practically no exudation takes place.

Transpiration and Exudation

1. In transpiration water escapes in the form of vapour; while in exudation water escapes in liquid form.

2. The water that escapes in transpiration is pure; while the water that escapes in exudation contains minerals in solution.

3. In transpiration water escapes through the stomata and to some extent through the cuticle; while in exudation water escapes through the hydathodes (see fig. 418) and water stomata (or water pores). Ordinary stomata are distributed all over the surface (commonly lower) of the leaf, while hydathodes and water stomata develop at the margin or apex of the leaf at the end of a vein.

4. Transpiration is regulated by the movement of the guard cells, partially or wholly opening or closing the stomatal aperture; while exudation cannot be so regulated, the guard cells of the water stomata having lost the power of movement.

5. Transpiration takes place in the presence of sunlight and, therefore, during the daytime; while exudation takes place in the absence of transpiration and, therefore, at night.

6. Transpiration secures concentration of sap, and also keeps the plant cool by dissipating the excess heat absorbed from sunlight; exudation has no such effect.

ASCENT OF SAP

The water absorbed from the soil by the root-hairs is conducted upwards to the leaves and the growing regions of the stem and the branches. A cut branch of lupin bearing white flowers dipped into eosin solution shows a gradual change in the colouration of flowers from white to pink within a few minutes. In herbaceous plants the height this water has to reach is small, but in some trees such as *Eucalyptus*, some conifers, etc., which may attain a height of over 300 ft.

or more, the distance to be traversed by this column of wa is considerable, and the water has to resist a consideral pressure to reach that height. The rate at which the tra piration current flows upwards through the vessels varies good deal in different plants, and at different times in the san plant. Generally speaking, the rate is about 1 to 2 metr per hour in healthy trees. Two questions naturally arise this connexion: what is the path of movement of sap and wh are the factors responsible for the ascent of sap?

Path of Movement of Sap. The path of movement of sa may be determined in one of the following two ways: (*a*) small herbaceous plant (*Peperomia*, for example) or a smal branch of a plant (lupin, for example) may be immersed in eosin solution. After a short time sections, cross and longi tudinal, are prepared from it at different heights and examined under the microscope. Sections will show the presence of coloured solution only in the vessels and tracheids. Therefore, these are the elements through which movement of sap, or **transpiration current** as it is called, takes place. (*b*) All the peripheral tissues right up to the phloem and cambium may be removed in the form of a ring (girdling) from a branch, leaving xylem intact. In a cut branch treated similarly the pith may also be crushed. It is seen that no wilting of leaves takes place. As it is only the xylem that remains intact we may conclude that ascent of sap takes place through it. This is known as 'ringing' experiment.

Factors Responsible for the Ascent of Sap. Various theories have been advanced from time to time to explain the ascent of sap, but none has proved satisfactory yet. It is believed that root-pressure forces up the water to a certain height, and that transpiration exerts a suction force on this column of water from above. In short, it may be said that root-pressure gives a 'push' from below and transpiration a 'pull' from above. In this respect transpiration is a more powerful factor. Probable theories regarding the ascent of sap are as follows:

1. **Root-pressure.** Root-pressure is alleged to be one of the forces responsible for the ascent of sap. Many plants are seen to eject water with great force (*bleeding*) when the stem is cut above the ground. This phenomenon has been explained as due to the osmotic pressure which operates in the root-cortex to produce the root-pressure. Root-pressure may be adequate to force up water in herbs, shrubs and low trees, and that too in the absence of transpiration. Root-pressure can only generate 2 atmospheres of pressure and thus raise a column of

water to a height of 20 metres (1 metre=39·37 inches); whereas a pressure amounting to more than 20 atmospheres is required to send the sap to the top of lofty trees, sometimes 300 feet or even more in height. Root-pressure is thus inefficient in this respect. The process is also slow and cannot keep pace with the water lost by transpiration; further, root-pressure is lowest when transpiration is highest; in fact, during active transpiration the water in the vessels is under a negative pressure. In many plants root-pressure is absent or feeble at certain times of the year. Besides, water still rises through the stem if the roots are decapitated and the cut end of the stem dipped into water.

The rôle of root-pressure in the ascent of sap has, however, been emphasized by White (1938). He has experimentally shown that excised tomato roots exude water with a pressure amounting to 6 atmospheres or even more. This pressure is sufficient to raise a column of water to a height of 180 feet or even more.

2. **Capillarity.** The level of water inside a capillary tube is always higher than the level outside; the smaller the bore of the tube, the higher will be the rise of water in it. Xylem vessels may be regarded as so many capillary tubes extending from the root to the leaf, but from the known diameter of the vessels it is obvious that the rise of water can hardly exceed a few feet. Further, the conducting elements in gymnosperms are so many tracheids with numerous transverse septa (and not vessels). Capillarity again implies free surface, but this is not found in plants as the vessels end in parenchymatous cells, and the water in the vessels is not in direct communication with the soil-water.

3. **Imbibition Theory.** Sachs (1874) suggested that water moves along the walls of xylem vessels (and not through their cavities) due to the imbibition force (see p. 291), and this is responsible for the ascent of sap in plants. But when the cavities of the vessels are artificially blocked with oil, air or gelatin the branches are seen to wilt showing thereby that the amount of water absorbed by this process cannot at all keep pace with the amount of water lost by transpiration. The force of imbibition is no doubt great but the movement of water by this process is slow.

4. **Vital Forces.** (*a*) Activity of living cells, *e.g.* wood parenchyma and medullary ray cells surrounding xylem, has been held by Godlewski (1884) to be responsible for the rise of sap through the plant body. The rôle played by the living cells is like that of relay pumps. The living cells take water from the vessels at a particular level and then force it again

into the vessels at a higher level, and the sap thus rises. Strasburger (1891), however, refuted the idea of vital force by killing the living cells by the application of heat as well as by poisonous chemicals.

(b) According to the late Sir J. C. Bose (1923) the ascent of sap is due to active *pulsation* of the internal layer of the cortex abutting upon the endodermis. This he proved with the help of a fine electric probe which was thrust into the stem step by step; the probe was connected with a galvanometer. When it reached that particular layer the pulsating activity was suddenly exhibited; on either side of the layer the activity suddenly disappeared. His conclusion was that due to the pulsating activity of the living cells of this layer a sort of pumping action is set up, and this is responsible for the *physiological* propulsion of the sap upwards through the stem. Conduction of water takes place through this layer even in the absence of root-pressure and transpiration. Xylem vessels being dead and inactive no pulsation is exhibited by them, and these were regarded by him as only reservoirs of water: mechanical transport of water according to him is only possible through them to some extent. The cortex injects water into them and withdraws it from them according to circumstances. All the living cells exhibit pulsation to a greater or less extent, but the activity of the internal cortex is exceptionally great. Anatomical and experimental evidence, however, does not support this view.

5. **Transpiration Pull and Force of Cohesion.** The understanding of the subject of ascent of sap was immensely advanced by Dixon in 1914. His theory consists in transpiration pull and tensile strength of water column. According to this theory water particles cohere together and form into a continuous column in the vessels from the root to the leaf with no air-bubbles in this column. Water particles cohere so strongly to one another that the column does not break forming bubbles anywhere in its entire length even under a state of tension due to transpiration pull. Cohesive power of water, as has been experimentally worked out, may be as great as 158 atmospheres of pressure, thus raising water to a height of 1,580 metres. There is no tree as tall as that and, therefore, this force is regarded as sufficiently powerful in this respect. As transpiration takes place from the leaf-surface the cell-sap of the mesophyll cells becomes concentrated and water is withdrawn from the tracheids of veins by the process of osmosis. Accordingly a pull is exerted on the end of the water-column, and the whole water-column is bodily pulled up.

CHAPTER VI

MANUFACTURE OF FOOD

Food of Plants. The substances that are more or less directly utilized by living organisms for their nourishment constitute their food. In this respect there is hardly any difference between the food of plants and that of animals ; both are nourished by the same types of chemical compounds, and these are always organic in nature. If inorganic materials are supplied to green plants these are ultimately converted into organic food materials which alone contribute to the nourishment of their body. Inorganic substances are raw materials and are not regarded as food of plants. We may say then that the organic compounds which are stored up in plants and are more or less directly utilized by them for their nourishment are to *be regarded as food. Such substances are* **carbohydrates, proteins** and **fats** and **oils.** Animals, non-green plants and non-green cells of plants have to depend directly or indirectly on the organic food prepared by the chloroplast-bearing cells of green plants. It is evident, therefore, that green plants hold a strategic position so far as food is concerned, or in other words, these are of utmost importance for the maintenance of life upon earth.

I. Carbohydrates

Photosynthesis. *Photosynthesis (photo,* light; *synthesis,* building up) *consists in the building up of simple carbohydrates such as sugars in the green leaf by the chloroplasts in the presence of sunlight (as a source of energy) from carbon dioxide and water absorbed from the air and the soil respectively.* The process is accompanied by a liberation of oxygen (see experiment 10). The volume of oxygen liberated has been found to be equal to the volume of carbon dioxide absorbed. But it is to be noted that all the oxygen liberated in the process is released exclusively from water (H_2O) and not from carbon dioxide (CO_2). Oxygen escapes from the plant body through the stomata. This formation of carbohydrates, commonly called **carbon-assimilation,** is the monopoly of green plants only, chlorophyll being indispensable for the process. By this process not only simple carbohydrates are formed but also a considerable amount of *energy* (initially obtained from sunlight as radiant energy) is transformed by green cells into chemical energy and stored up as such in organic substances formed. It must be noted that photosynthesis takes place only in the green cells

and, therefore, mainly in the leaf and to some extent also in the green shoot. Under favourable conditions of light intensity and temperature the rate of photosynthesis increases enormously and a tremendous amount of CO_2 is absorbed from the air for this process, so much so that on a windless day the CO_2 content of the air over a field crop may drop to 0.01% from normal 0·03%.

Mechanism of Photosynthesis. The intermediate chemical stages in the process have still remained a mystery. Numerous researches carried out over a long period have failed to trace the different chemical reactions involved in the production of carbohydrates from carbon dioxide (CO_2) and water (H_2O), and there has been a great deal of speculation, too, in the matter. It has been suggested that glucose $C_6H_{12}O_6$ is formed as follows:—$6CO_2 + 12H_2O \rightarrow C_6H_{12}O_6 + 6H_2O + 6O_2$. This over-all reaction does not, however, explain the chemical changes taking place in the green cells. In fact these changes are not definitely known yet. Photosynthesis takes place in a series of chemical reactions—some are photo-chemical requiring light energy and some are chemical or enzymic requiring a particular temperature. Chlorophyll no doubt is indispensable for photosynthesis, but it is not known what exact rôle it plays in the process excepting that (*a*) it absorbs radiant (light) energy and possibly also transfers this energy to the photosynthetic products, and (*b*) it acts as a catalytic agent, itself undergoing no change during the photosynthetic process. External factors like light, carbon dioxide and temperature are most essential for proper functioning of the chloroplasts. Probably several enzymes, though none isolated yet, also play a part in several stages of the process.

It was formerly believed (Baeyer, 1870) that CO_2 and H_2O are broken up by the chloroplasts in the presence of *light* and suitable *temperature*, and some chemical changes take place resulting in the formation of *formaldehyde* (*CH_2O*) as an intermediate product and in the liberation of oxygen according to the following reaction: $CO_2 + H_2O \rightarrow CH_2O + O_2$. Formaldehyde is an unstable compound and a strong poison. So as soon as it is formed, it was believed, it becomes converted into sugar, probably glucose, by a process known as **polymerization**, i.e. condensation of several molecules. Thus six molecules of formaldehyde condense to form one molecule of glucose according to the following reaction: $6CH_2O \rightarrow C_6H_{12}O_6$ (glucose). Finally glucose becomes converted into starch, as represented by the following reaction: $n(C_6H_{12}O_6) \rightarrow (C_6H_{10}O_5)n + n(H_2O)$. But this formaldehyde theory has now been altogether discarded.

In recent years with the discovery of radioactive elements, particularly radioactive carbon, C^{14}, it has been possible to some extent to trace the sequence of compounds through which the carbon dioxide passes on its way to the final products formed during the process of photosynthesis. This is called 'tracer'

method. The sequence has definitely proved that a simple reaction, as shown by Baeyer, does not take place and that formaldehyde is not formed. A very important initial discovery made by Hill (1937) and subsequently corroborated by Ruben and others (1941, 1943) in connexion with photosynthesis by using radioactive oxygen, O^{18}, in water (H_2O^{18}) is that oxygen released in the process comes exclusively from water and not from CO_2 as hitherto believed. Similarly by using carbon dioxide which contains radioactive carbon of atomic weight 14, i.e. $C^{14}O_2$, it has been possible to trace the 'marked' carbon through successive reactions. Thus in 1950 Benson and Calvin by using $C^{14}O_2$ (with radioactive carbon in it) succeeded in tracing it through some of the intermediate stages of photosynthesis. They found that when the period of photosynthesis, i.e. the period of exposure to light, was shortened to a few seconds a detectable quantity of phosphoglyceric acid was formed. Phosphoglyceric acid is, therefore, the first stable intermediate product formed in photosynthesis. It is a 3-carbon compound and possibly it is formed from an unknown 2-carbon compound. The radioactive carbon used in the experiments could be traced in the phosphoglyceric acid and finally in the sugar formed in the process. That such a reaction takes place leading to the formation of phosphoglyceric acid has also been corroborated by others working on this problem. But exactly how sugar appears is not clear. It is possible that the union of two such 3-carbon compounds produces a 6-carbon compound which is sugar. The over-all reaction may be represented thus: $6CO_2 + 12H_2O \rightarrow C_6H_{12}O_6 + 6H_2O + 6O_2$. The nature of the whole process of photosynthesis seems to be very complex. It is evident that the process passes through several steps with the formation of a series of intermediate compounds whose nature is still obscure.

It may be mentioned that after a short period of photosynthesis radioactive carbon is also found in pyruvic acid which is a phosphoglyceric acid derivative of sugar. This pyruvic acid holds a key position in the metabolism of the cell. It may [illegible] converted to certain amino-acids and [illegible] acids, and to fats. In respiration the [illegible] ed to CO_2 and H_2O. It is thus made [illegible] and fats is connected with the inter[illegible], and that respiration is a reverse process of photosynthesis, both following similar courses of reactions in the opposite directions.

Photosynthesis as a whole resolves itself into two main pro[illegible] cesses with several reactions—the first process is photo-chem[illegible] requiring light energy and the second is chemical or [illegible] depending on temperature. The process of photosyn[illegible] initiated with the absorption of light energy by chloro[illegible] utilization of this energy in breaking up water [illegible]

oxygen and hydrogen. It has been already stated that all the oxygen released in photosynthesis comes exclusively from H_2O. Oxygen escapes, while hydrogen is stored in small quantities in the chloroplasts in combination with some unknown compound which acts as an acceptor of hydrogen. By this process the light energy originally obtained from sunlight is converted into potential chemical energy. The second process consists in the transfer of hydrogen to CO_2 (which now acts as an acceptor of hydrogen) to form a 3-carbon compound—phosphoglyceric acid, as stated before. Finally the phosphoglyceric acid becomes transformed into sugar. The second process may proceed in the dark and in the non-green cells. Nearly the whole of CO_2 taken up in photosynthesis enters into the composition of sugar. Sugar is almost immediately converted into starch.

Different kinds of atoms of a particular element having different atomic weights but identical chemical properties are called **isotopes.** For example, there are different kinds of carbon atoms with atomic weights of 10, 11, 12, 13 and 14 respectively. All isotopes are not radioactive. Some of the heavy elements like uranium and radium are naturally radioactive, while the staple isotopes of many elements can be artificially made radioactive. Thus the atomic weight of stable carbon is 12, while that of the artificially made radioactive carbon may be C^{10}, C^{11}, C^{13} or C^{14}. All radioactive elements disintegrate by the loss of charged particles and by radiation. The life of such an element is, therefore, unstable varying in duration from a second or even less to thousands of years. From a biological standpoint radioactive elements have proved to be of immense value in elucidating certain intricate problems of plant-life and animal-life because it has been possible to trace such 'marked' elements through successive stages in the plant body or the animal body. Thus radioactive carbon could be traced in the intermediate and final products formed in the process of photosynthesis. This evidently helps us to ascertain the nature of the products that appear during the process. Atomic weights of some of the radioactive elements used in plant research are C^{11}, C^{14}, O^{18}, S^{35}, P^{32}, K^{42} and Ca^{45}, their corresponding stable forms being C_{12}, O_{16}, S_{32}, P_{31}, K_{39} and Ca_{40}.

End Products in Photosynthesis. Oxygen and starch are the final products formed in photosynthesis. Oxygen escapes from the leaf (see experiment 10) but starch accumulates ih it (see experiment 11). Starch may be detected in the following way. In the evening collect one or more leaves and bleach them with methylated spirit. Then dip them into iodine solution. They are seen to turn bluish-black in colour indicating the presence of starch grains. It is better to treat the leaves further with benzol for a few minutes. The brownish colour of the leaves due to the action of iodine solution on protoplasm and cellulose disappears, and the bluish-black colour of starch grains stands out clearly. Starch is insoluble in water. At night it is converted into sugar by the action of an enzyme known as diastase and translocated to storage organs. In the storage tissues sugar is reconverted into starch by the leucoplasts.

Experiment 10. Photosynthesis: to show that oxygen is given off during photosynthesis (fig. 477). Place some green submerged water plants (e.g. *Hydrilla*) in a large beaker filled with water. Add a small quantity of soda water or a pinch of soda bicarbonate as a source of carbon dioxide. Cover the plants under water with a glass funnel, and invert over the funnel under water a test-tube filled with water. It is better to cut the stems and tie up the shoots into a bundle. The cut ends should be projected upwards into the funnel.

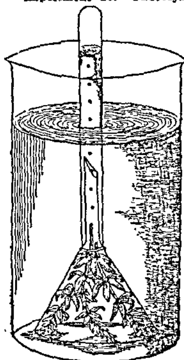


FIG. 477. Evolution of oxygen bubbles in photosynthesis of submerged water plants (*Hydrilla*).

Observation. When exposed to bright light a stream of small gas bubbles is seen to rise upwards through the cut ends of stems and collect at the upper end of the test-tube, displacing the water. If the apparatus be removed to a dark or semi-dark room or covered with black paper, no bubbles will be seen to come out of the plants.

Inference. That the gas is oxygen can be proved in the following way. Close the test-tube with the thumb under water, and invert it over a dish containing a quantity of pyrogallate of potash (5% pyrogallic acid to which an excess of caustic potash has been added). Then with the help of a bent tube introduce into the test-tube a quantity of this solution. The pyrogallate solution coming in contact with the gas will absorb it and will, therefore, rise and completely fill up the test-tube. The pyrogallate solution absorbs oxygen. The gas in the tube is, therefore, oxygen.

Experiment 11. Photosynthesis: to demonstrate that starch is formed in photosynthesis (figs. 478-9). Select a healthy green leaf of a plant *in situ* and cover a portion of it on both sides with two uniform pieces of black paper, fixed in position with two paper-clips, either in the morning before the sun rises or the previous evening, so that the experiment is performed with a starch-free leaf. Or, keep a healthy, green pot plant in a dark room for 1 or 2 days so that its leaves become starch-free, and then cover a portion of a leaf of this plant as described above. Fix the pieces of paper properly with paper-clips or soft wooden clips. To make sure that there is no starch, collect a few neighbouring leaves in the morning, decolorize them with alcohol and dip them into iodine solution.

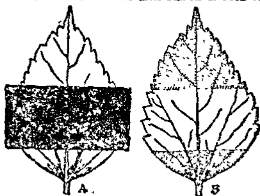


FIG. 478. Formation of starch grains in photosynthesis of land plants. A, leaf partially covered with black paper; B, covered portion without starch grains while uncovered portions with plenty of them.

You will see that they do not turn black. Evidently all the leaves are starch-free. Now let the plant be exposed to light for some time, preferably till the evening. Then collect the leaf and decolorize it with alcohol. Place the blanched leaf in iodine solution for a minute or so. Note that the exposed portion turns blue or black showing the presence of starch in it. The screened portion, on the other hand, turns yellowish brown, there being no starch formed in it; this yellowish brown colour is due to the action of iodine solution on protoplasm and cellulose. It is better to place the iodine-treated leaf in benzol for a few minutes. Benzol removes the brownish colour from the protoplasm and the cell-walls, and then the bluish-black colour of starch becomes clear.



Fig. 479. Starch print in photosynthesis.

A very interesting experiment known as the **starch print** (fig. 479) may be carried out in the following way. A stencil (which may be a blackened thin tin plate or a black paper) with the letters S T A R C H punched or cut in it is used for this purpose, the procedure being the same as described under experiment 11. Later, when the leaf is dicolourized and treated with iodine solution, the print of S T A R C H will stand out boldly in black on the bleached leaf owing to the formation of starch grains with the access of light, turning black in contact with iodine.

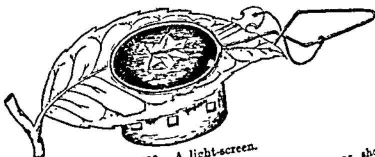


Fig. 480. A light-screen.

Instead of loose black paper or stencil a light-screen, as shown in fig. 480, may be used to cover a portion of the leaf. The advantage of the light-screen is that it allows free ventilation and at the same time cuts off all light.

NOTE. The above experiments also show that photosynthesis takes place *only in the presence of sunlight.*

Experiment 12. *To show that plants cannot photosynthesize unless carbon dioxide is available*: Moll's experiment (fig. 481). Take a wide-mouthed bottle and a split cork of appropriate size. Pour a small quantity of caustic potash solution into the bottle and lay it on its side. Before sunrise cut out a *healthy green leaf, evidently starch-free*, and place it—half inside the bottle and half outside—between the two halves of the split cork, with the petiole dipped into water. Smear the edges of the split cork with vaseline to make the bottle air-tight. The whole apparatus is then exposed to direct sunlight till the evening. Then remove the leaf, decolorize it with methylated spirit and dip it into iodine solution. It will be seen that the portion of the leaf lying outside the bottle turns black; while the portion inside the bottle turns yellowish. This evidently shows that no starch grains are formed when carbon dioxide is not available, all the carbon dioxide contained in the bottle having been absorbed by *the caustic potash solution*. (A pot plant, preferably *Crinum* or *Amaryllis*, will also serve the purpose very well. The pot plant may be kept in a dark room for one or two days to make the leaves starch-free. The experiment may then be carried out in the above way without cutting out the leaf.)

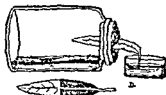


FIG. 481. Moll's experiment on photosynthesis.

Experiment 13. To show that chlorophyll is essential for photosynthesis. Select a garden croton plant with variegated leaves. Cut out a small branch from it and dip the cut end into water in a bottle. Keep it in a dark room for 1 or 2 days to free the leaves of starch grains. Then mark the green portions in 1 or 2 leaves, expose the branch to bright sunlight for the whole day. In the evening collect the marked leaves, decolorize them with methylated spirit and put them into iodine solution. *Note that only the green portions of the leaf turn black indicating the* presence of starch grains; while the non-green portions turn yellowish. It is, therefore, evident that without chlorophyll photosynthesis cannot take place.

Conditions necessary for Photosynthesis

Light intensity, temperature and carbon dioxide concentration of the air are the three most important external conditions for photosynthesis and its rate.

1. **Light.** This is the most important condition for photosynthesis. *Formation of carbohydrates cannot take place* unless light is admitted to the chloroplasts. Naturally the process is in abeyance during the night. If a leaf or any part of it be covered with black paper starch grains are not formed there (see experiment 11). The rate of photosynthesis also varies according to the intensity of light. In very weak light no starch grains are formed. Too intense light also has the same effect.

2. **Carbon dioxide.** Carbon dioxide of the air is the source of all the carbon for the various organic products of the plant, such as sugar, starch, etc., and, therefore, the process is in abeyance if carbon dioxide be not available to the plant (see experiment 12). Under favourable conditions of light and

temperature if carbon dioxide concentration rises from 0·03 per cent in the air to 0·1 per cent or even more, carbohydrate formation greatly increases.

3. **Temperature.** Photosynthesis takes place within a wide range of temperature. It goes on even when the temperature is below the freezing point of water, but the maximum temperature lies somewhere at 45°C. The optimum temperature, i.e. the most favourable temperature for photosynthesis, may be stated to be 35°C. Both maximum and optimum temperatures, however, vary in different species of plants and in those growing under different climatic conditions.

4. **Chlorophyll.** This is essential for photosynthesis; the plastids are powerless in this respect without the presence of chlorophyll. For the same reason non-green parts of plants cannot photosynthesize (see experiment 13). Fungi and saprophytic and parasitic phanerogams have altogether lost this power, being devoid of chlorophyll.

5. **Potassium.** Potassium helps synthesis of carbohydrates and, therefore, in the absence of potassium salts starch grains are not formed. Potassium does not enter into the composition of carbohydrates but acts as a catalyst helping in their synthesis.

6. **Water.** Water is indispensable for photosynthesis because water and carbon dioxide undergo chemical changes leading to the formation of carbohydrates under the influence of chloroplasts and in the presence of sunlight. It is, however, a fact that less than 1 per cent of the water absorbed by the roots is utilized in photosynthesis. Besides, water makes the photosynthetic cells turgid and active.

Limiting Factors in Photosynthesis. The principle of limiting factors was enunciated by Blackman in 1905. He showed
, de concentration and temperature
osynthesis, i.e. the ultimate rate
by each such factor. Just as the strength of a chain is determined by its weakest link, so the rate of photosynthesis is controlled and limited by the least favourable factor. Under normal condition of 0·03% concentration of CO_2 in the air and within a certain range of temperature photosynthesis may start with low intensity of light. Supposing then that the said concentration of carbon dioxide remains constant, with increasing light intensity the rate of photosynthesis steadily increases until a particular maximum is reached. Without further increase in CO_2 concentration the rate of

photosynthesis shows no further progress even if the light intensity is increased. It is evident then that at this point carbon dioxide acts as a limiting factor. Supposing again that light intensity remains constant it is seen that with increasing supply of CO_2, say from 0·03% to 0·5-1% or even more, the rate of photosynthesis will rise again up to a certain point. Further increase in CO_2 concentration under the same condition of light intensity will have no influence on the rate of photosynthesis. At this point light acts as a limiting factor. Different concentrations of CO_2 are correlated with different intensities of light i.e. more intense light is required to utilize more concentrated carbon dioxide. But then there is a limit beyond which each factor inhibits the rate and may even check the process altogether. Within a certain range the effect of temperature on the rate of photosynthesis shows very little variation. But it has been noted that with low intensity of light, even if the concentration of CO_2 be high, the rate of photosynthesis does not appreciably increase with increase in temperature. With high light intensity, however, even if the CO_2 concentration be low, the rate of photosynthesis increases with increasing temperature until a particular point is reached.

Conditions necessary for the Formation of Chlorophyll

A number of factors, both internal and external, are responsible for the formation of chlorophyll. In the absence of any of them chlorophyll synthesis is in abeyance.

1. **Light.** Without light chlorophyll cannot develop; continued absence of light decomposes chlorophyll. Many algae, mosses and ferns, and seedlings of conifers and of some angiosperms develop chlorophyll and become green in colour in the dark. In the light, however, more chlorophyll develops than in the dark. Normally in the absence of light plants develop **etiolin**, a pale-yellow pigment, instead of chlorophyll. Plants under this condition are said to become *etiolated*. Very strong light also decomposes the chlorophyll in the leaf, particularly in shade-loving plants.

2. **Temperature.** Chlorophyll develops within a wide range of temperature, the maximum rate usually varying from 26-30°C.; very high temperature—45-48°C.—decomposes chlorophyll.

3. **Iron and Magnesium.** In the absence of the salts of these metals chlorophyll is not formed, and seedlings assume a sickly yellow appearance. In this condition they are said to be *chlorotic*. Although both iron and magnesium are required

for the formation of chlorophyll it is only magnesium that enters into its composition.

4. **Manganese.** It is also believed that manganese is necessary, even essential, for the formation of chlorophyll.

5. **Nitrogen.** Nitrogen enters into the composition of chlorophyll and, therefore, in the absence of nitrogen chlorophyll fails to develop.

6. **Water.** Leaves, when they dry up in the absence of water, are seen to lose their green colour. Desiccation thus brings about decomposition of chlorophyll. In prolonged droughts leaves of many plants, particularly of grasses, turn brownish in colour.

7. **Oxygen.** It is also necessary for the formation of chlorophyll. Etiolated seedlings fail to develop chlorophyll in the absence of oxygen, even when these are exposed to sunlight. Chlorophyll formation is, therefore, an oxidation process.

8. **Carbohydrates.** Cane-sugar, grape-sugar, etc., are also necessary for the formation of chlorophyll. Etiolated leaves without soluble carbohydrates in them, develop chlorophyll and turn green in colour when floated on sugar solution.

9. **Heredity.** This is a powerful factor and determines the formation of chlorophyll in the offsprings. Familiar examples are garden crotons, some varieties of aloes, maize, screwpine, aroids (e.g. *Caladium*), amaranth (*Amaranthus*), etc.

Chemistry of Chlorophyll. Chlorophyll, as it exists in the chloroplasts, is a mixture of four different pigments. The pigments are as follows:

1. Chlorophyll *a*, $C_{55}H_{72}O_5N_4Mg$—a blue-black micro-crystalline solid.
2. Chlorophyll *b*, $C_{55}H_{70}O_6N_4Mg$—a green-black micro-crystalline solid.
3. Carotin, $C_{40}H_{56}$—an orange-red crystalline solid.
4. Xanthophyll, $C_{40}H_{56}O_2$—a yellow crystalline solid.

Effect of Rays of Light on Photosynthesis. It is a known fact that white light is composed of seven colours arranged in the following order: red, orange, yellow, green, blue, indigo and violet. Although photosynthesis normally takes place in white light, it is only a few of the above rays that are required for this function. Chlorophyll normally utilizes a large portion of the red ray and also orange and blue-violet rays. Green and other rays are not utilized to any extent; in other words, chloroplasts are most active in red, orange and blue-violet rays, much less so in any of the other rays mentioned [illegible]: in a general way by covering a green [illegible] bell-jar which has been filled with a solu[illegible] other colour, then exposing the plant to [illegible] finally testing the leaves with iodine solu[illegible], or their absence, will be evident from the blue or black colour, or its absence. The intensity of colour depends on the quantity of starch accumulated. In the case of the water plants the effects of rays of light may similarly be studied from the rate of evolution of oxygen bubbles.

II. Proteins

Nature of Proteins. These are very complex organic nitrogenous compounds found in plants. Analyses of proteins show that carbon, hydrogen, oxygen, nitrogen, and often sulphur and phosphorous enter into their composition, but we know little about their molecular structure. Protein molecules are very large and extremely complex consisting of hundreds or thousands of atoms and are composed of several chains of amino-acid molecules. Besides these essential elements, small quantities of sodium, potassium, magnesium and iron are also present. Various kinds of proteins are found in plants. Most of them are very complex in their chemical composition. Amines and amino-acids are the initial stages in the formation of proteins, and these are also the decomposition products of the latter.

Synthesis of Proteins. Proteins are normally formed from nitrates absorbed from the soil. But the chemical reactions leading to the formation of these complex compounds are only imperfectly known. Protein synthesis mostly takes place in the meristematic and storage tissues; some proteins are also formed in all active cells of the plant body. It is believed that the whole process of protein synthesis takes place in three different stages. (*a*) **Reduction of Nitrates.** Nitrates, after these are absorbed into the plant body, are first reduced to nitrites, and the latter are further reduced to ammonia (amino group, $-NH_2$), as follows: $-NO_3 \rightarrow -NO_2 \rightarrow -NH_2$. This reduction takes place either in the root or in the leaf. (*b*) **Synthesis of Amino-acids.** This ammonia (amino group, $-NH_2$) then combines with sugar or some intermediate products of carbohydrate metabolism (photosynthesis and respiration), which supply the necessary carbon, hydrogen and oxygen in the building up of amino-acids. The amino-acid, cystine, which is formed in all plants, also contains sulphur. There are over 20 different amino-acids known to be constituents of plant proteins. Amino-acids are mainly formed in leaves and stem-tips. (*c*) **Synthesis of Proteins.** Protein molecules are very large and complex. A protein molecule may be finally formed by linkage of hundreds or thousands of amino-acid molecules which may be arranged in the former (protein molecule) in practically infinite varieties of ways. According to Emil Fischer proteins are formed by condensation of numerous amino-acids under the action of some enzymes. As the hydrolyzing enzymes break down proteins into amino-acids during the germination of seeds, in the reverse way these enzymes condense back the amino-acids into proteins. Complex

proteins contain sulphur and phosphorus also. These elements are supplied by sulphates and phosphates obtained from the soil. In some plants amino-acids are mainly formed in the roots. They travel from there to distant tissues, and protein synthesis mostly occurs in the meristematic and storage tissues. Proteins, however, do not travel as such.

III. Fats and Oils

The different stages in the formation of fats and oils are not clear. It is believed that they are synthesized from glycerine and fatty acids under the action of the enzyme *lipase*. Both glycerine and fatty acids are derived from carbohydrates. The process is independent of light and chlorophyll. See also pp. 195-6.

CHAPTER VII

SPECIAL METHODS OF OBTAINING FOOD

Green plants are **autotrophic** (*auto*; self; *trophe*, food) or self-nourishing, that is, they are able to manufacture carbohydrates from raw or inorganic materials and thus nourish themselves. Non-green plants on the other hand are **heterotrophic** (*heteros*, different). Such plants cannot prepare carbohydrates and nourish themselves. They get their supply of carbohydrate food from different sources. They can, however, prepare other kinds of food. Heterotrophic plants are **parasites** when they depend on other living plants or animals, and they are **saprophytes** when they depend on the organic material present in the soil or in the dead bodies of plants and animals.

1. **Parasites** (see pp. 42-4). Total parasites, like dodder (*Cuscuta*), broomrape (*Orobanche*), etc., are never green, and consequently they have no power to prepare their own food. Thus they draw in all their nourishment from the host plant on which they are parasitic. Partial parasites like mistletoe (*Viscum*), *Loranthus*, *Cassytha*, etc., on the other hand, are green in colour and are, therefore, not entirely dependent on the host plant. Parasitic phanerogams develop haustoria or sucking roots which go into the vascular bundles of the host plant and absorb from them the prepared food materials and water. Fungi as a class are either total parasites or saprophytes. Parasitic fungi send their mycelia into the tissues of the host plant. The mycelia ramify in all directions, and absorb the necessary food materials.

2. **Saprophytes** (see pp. 45-6). Saprophytic phanerogams such as Indian pipe (*Monotropa*—see fig. 72), some orchids,

and saprophytic fungi such as *Mucor* grow on decaying animal or vegetable matter, and absorb nutriment from it.

3. **Symbionts** (see p. 46). Two organisms living in close association with each other being of mutual benefit are called symbionts, and the condition is known as symbiosis. Lichen, mycorrhiza, etc., are illustrative examples.

4. **Carnivorous Plants.** These plants are known to capture lower animals of various kinds, particularly the insects. They digest the prey and absorb the nitrogenous products (proteins) from their body. Being green in colour they can manufacture their own carbohydrate food. Altogether over 450 species of carnivorous plants have till now been discovered representing 15 genera belonging to 6 families; of them over 30 species are found to occur in India. According to the mode of catching the prey they may be classified into four groups:

(*a*) Plants with sensitive glandular hairs which exude a sweet viscid substance, e.g. sundew and butterwort.

(*b*) Plants with special sensitive hairs—trigger hairs—on the leaf-surface, e.g. Venus' fly-trap and *Aldrovanda*.

(*c*) Plants with leaves modified into pitchers, e.g. pitcher plant.

(*d*) Plants with leaf-segments modified into bladders, e.g. bladderwort.

Of these, bladderwort and *Aldrovanda* are aquatic plants.

(1) **Sundew** (*Drosera*; fig. 482)—90 sp. Only 3 species have been found in India. They are small herbs—a few inches in height. Each leaf is covered on the upper surface with numerous glandular hairs known as the **tentacles.** Each gland secretes a kind of viscous fluid which glitters in the sun like dew-drops and hence the name 'sundew'. The gland is sensitive and reacts only to chemical stimulus; this means that movement of the tentacles is initiated by the presence of nitrogenous substances. No movement is exhibited by contact with any foreign object. When any insect mistaking the glistening substance for honey alights on the leaf, it gets entangled in the sticky fluid, and the tentacles stimulated by

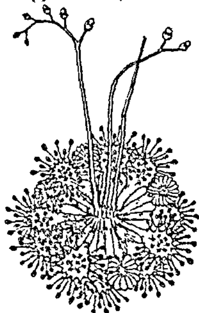


FIG. 482. Sundew (*Drosera*).

the digestible compounds present in the body of the insect bend down on it from all sides and cover it. When it is suffocated to death the process of digestion begins. The tentacles remain bent over the insect until all the nitrogenous compounds contained in its body have been absorbed. Digestion is extracellular in all carnivorous plants. The glands secrete an enzyme, called *pepsin hydrochloric acid*, which acts on the insect and changes the proteins of its body into soluble and simple forms. The products of digestion are then absorbed by the leaf. The carbonaceous materials are rejected in the form of waste products.

If the tentacles be poked with any hard object, they show no movement nor any secretion of the enzyme takes place. On the other hand, if a bit of raw meat be placed on the leaf, the tentacles bend over it and the glands begin to secrete the enzyme.



FIG. 483. Butterwort (*Pinguicula*).

(2) **Butterwort** (*Pinguicula*; fig. 483)—30 sp. Only 1 species has been recorded from India, and that is *Pinguicula alpina*. It grows in mossy beds in the alpine Himalayas at an altitude of 11,000 to 13,000 ft. The species of butterwort are small herbs with a scanty development of roots. The surface of the leaf is covered with numerous glands—some sessile and some stalked, the former being water-secreting and the latter mucilage-secreting in nature. When any small insect alights on the leaf, it gets caught by the sticky glands. Stimulated by the presence of proteins in the insect body the margins of the leaf roll inwards enclosing it. The sessile glands then begin to secrete *pepsin hydrochloric acid* which carries on the digestion of proteins. Digested products are then absorbed by the plant. After digestion and assimilation the leaf unrolls itself again. Carnivory in butterwort was studied by Darwin who found that meat, egg-white, cartilage, small seeds, pollen grains and other substances containing nitrogen, when placed on the leaf, caused secretion of the enzyme, while those containing no nitrogen excited no secretion.

(3) **Venus' Fly-trap** (*Dionaea*; fig. 484)—1 sp. The plant is a native of the U.S.A. It is herbaceous in nature and grows in damp mossy places. Each half of the leaf-blade is provided

with three long pointed hairs—trigger hairs—placed triangularly on the leaf-surface. The hairs are extremely sensitive from base to apex. The slightest touch to any of these hairs

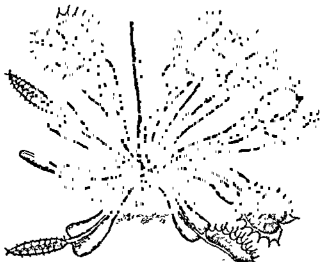


FIG. 484. Venus' fly-trap (*Dionaea*).

is sufficient to bring about a sudden closure of the leaf-blade, the mid-rib acting as the hinge. The upper surface of the leaf is thickly covered with reddish digestive glands. When the insect is caught, or any nitrogenous material such as meat, fish, etc., placed on the leaf, it closes suddenly and the glands begin to secrete the enzyme *pepsin hydrochloric acid*. The enzyme then brings about the digestion of proteins contained therein. The acid is stronger in this case than in most other carnivorous plants.

(4) *Aldrovanda* (figs. 485-6)—1 sp. This plant is very widely distributed over the earth. It has been found in abundance in the salt-lakes of the Sundarbans, salt-marshes—south of Calcutta, fresh water 'jheels' of East Pakistan and in several

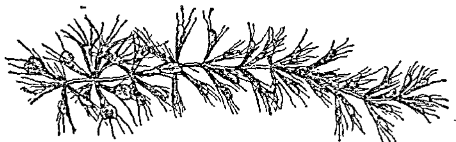


FIG. 485. *Aldrovanda*.

tanks in Manipur. *Aldrovanda* may be regarded as a miniature *Dionaea* in some respects. It is a rootless, free-floating plant with whorls of leaves. The mechanism of catching the prey is practically the same as that of *Dionaea*, but instead of only six sensitive hairs there is a number of them here on either side of the mid-rib, and the leaf is protected by some bristles. There are, of course, numerous digestive glands on the upper surface of the leaf, and the margins beset with minute teeth pointing inwards.

(5) **Pitcher Plant** (*Nepenthes*; figs. 487 and 152-3)—60 sp. Only 1 species (*Nepenthes khasiana*) has been found in India (in the Khasi, Jyntea and Garo hills). Pitcher plants are herbs or climbing undershrubs which often climb by means of tendrils. The pitcher itself is the modification of the leaf-blade, the tendrillar stalk supporting the pitcher is the modification of the petiole, and the laminated structure that of the leaf-base. Each pitcher varies from 4 to 8 inches or even more in height. When it is young the mouth of the pitcher remains closed by a lid which afterwards opens and stands more or less erect. Below the mouth the inside of the pitcher is covered with numerous, smooth and sharp hairs, all pointing downwards. Lower down, the inner surface is studded with numerous, large, digestive glands, each with a hood hanging down over it. Animals, as they enter, slip down the smooth surface, having lost their footing, and get drowned in the fluid that partially fills the cavity of the pitcher. After their death the process of digestion commences. The digestive power of the pitcher of *Nepenthes* was first discovered by Hooker in 1874. The digestive agent, secreted by the glands, is in the nature of a *trypsin*, as was first shown by Vines in 1877. It not only digests the proteins into peptones, but also changes the latter into amines. Amines are readily absorbed by the pitcher. Bits of egg-white, meat, etc., dropped into the pitcher, as was first found by Hooker are seen to be dissolved

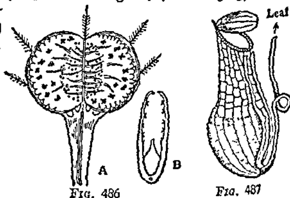


Fig. 486. *Aldrovanda*; *A*, an entire leaf open; *B*, section of a closed leaf. Fig. 487. A pitcher of pitcher plant (*Nepenthes*). See also figs. 152-3.

and ultimately absorbed in the form of amines. Carbohydrates and other materials remain undigested in the pitcher as waste products.

Bladderwort (*Utricularia*; fig. 488)—210 sp. Over 20 species have been found to occur in India. They are mostly

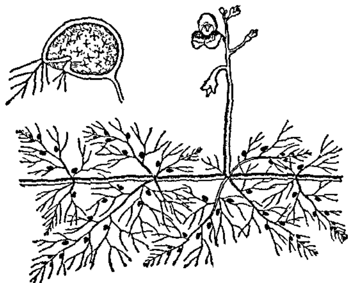


FIG. 488. Bladderwort (*Utricularia*) with many small bladders; *top*, a bladder in section (magnified).

floating or slightly submerged, rootless, aquatic herbs; there are a few terrestrial species also. The leaves are very much segmented, and these simulate roots excepting that they are green in colour. Some of these segments become transformed into *bladders*. Each bladder is about one-eighth inch in diameter and is provided with a trap-door entrance. The trap-door acts as a sort of valve which can be pushed open inwards from outside, but never from inside to outside. Very small aquatic animals enter by bending the free end of the valve which easily gives way. After their entrance the valve shuts itself automatically, leaving no chance for them to escape. The inner surface of the bladder is dotted all over with numerous digestive glands which vary somewhat in shape. Their function is to secrete the digestive agent and absorb the digested products. A bit of raw meat, pushed inside the bladder, is found to disappear within a few days.

CHAPTER VIII

TRANSLOCATION AND STORAGE OF FOOD

TRANSLOCATION

Food materials are prepared mostly in the leaves. From there these are translocated to the storage organs, which often lie at a considerable distance. There are definite and distinct channels in plants for the translocation of raw and prepared food materials—xylem vessels and tracheids for the transmission of raw or inorganic materials in the upward direction from the roots to the leaves, and sieve-tubes and associated cells for downward transmission of prepared food materials from the leaves to the storage organs. Thus dissolved proteins, and sugars, amines and amino-acids travel downward through the sieve-tubes and to some extent through the phloem parenchyma. Such materials can easily pass through the perforated sieve-plates. The protoplasmic threads extending through the pores in the sieve-plates also help in this respect. The companion cells are used to transmit food substances sideways to the medullary ray cells, the xylem parenchyma and the surrounding cells.

Soluble nitrogenous substances and soluble carbohydrates (sugars) after they are formed in the mesophyll of the leaf move by slow diffusion towards the vascular bundles. They pass through the border parenchyma and enter into the phloem. Phloem extends through the whole length of the plant body so that any soluble compound can be easily transported from the leaves to most of the organs, particularly the storage ones. In the storage organs complex proteins and starch grains are formed, and a gradual accumulation of them takes place in these organs. Later during the period of active growth—formation of buds and flowers—the various forms of stored food are rendered soluble and, therefore, suitable for travelling. Now an upward movement of the soluble food materials takes place through the phloem and finally these are brought to the growing organs. At this time of active growth a part of the food also moves upward through the xylem. The forces responsible for the downward or upward movement of food through the phloem are not known.

That phloem is definitely the principal channel for conduction of food can be proved by chemical analysis of its contents. Such analysis reveals the presence of soluble carbohydrates (sugars), proteins and other nitrogenous compounds in it.

Besides, by 'ringing' or 'girdling' experiments it can be shown that the phloem is the main conduction channel through which the food is primarily moving downwards. Thus if a ring of bark completely encircling a branch be removed down to the wood (evidently including phloem), swellings and later buds appear just above the ring or girdle due to accumulation of food which cannot move further down, phloem having been removed. If such a girdle be made at the base of a flowering branch, very large flowers and fruits may be produced for the same reason. Similarly, if a ring of bark be removed from the lower end of a cut leafy branch (say, of garden croton) and the cut end dipped into water, roots are seen to develop only above the girdle where food has accumulated, phloem having been removed with the ring. These experiments prove that phloem is responsible for carrying food materials downwards.

STORAGE OF FOOD

Food is prepared in excess of the immediate need of plants. This surplus food exists in plants in two conditions—either *suitable for travelling or suitable for storage*. The travelling form is characterized by *solubility*, and the storage form by *insolubility* in the cell-sap.

Storage Tissues. Tissues meant for storage of food have thin cellulose walls. The cells are mostly parenchymatous in nature. If the walls are thick they are provided with many simple pits in them. Storage cells are also living so that the protoplasm can secrete the necessary enzymes and render the food materials soluble or insoluble, according as translocation or storage is required. All parts made of large-celled parenchyma always contain a certain amount of stored food. Cortex of the root is particularly rich in it, and so also the large pith of the monocotyledonous root. There is also a quantity of food stored up in the endodermis, pith, medullary rays and xylem parenchyma of the stem. Border parenchyma of the leaf also has a storage of food in it.

Storage Organs. Food materials are stored up in the endosperm or in the thick cotyledons of the seed for the development and growth of the embryo. In the fleshy pericarp of the fruit there is a considerable amount of food stored up. Food is specially stored up in the fleshy roots such as the fusiform, napiform, conical and other roots, and in the underground modified stems such as the rhizome, tuber, corm, etc. All fleshy stems and branches, as in many cacti and spurges (*Euphorbia*), succulent leaves, as in Indian aloe (*Aloe vera*),

American aloe (*Agave*), purslane (*Portulaca*), etc., and fleshy scales of onion always contain a store of food in them. The swollen stem-base of kohl-rabi and the gouty stem of *Jatropha podogarica* also contain stored food. Stores of food may also be detected in the growing regions and in the floral organs.

Forms of Stored Food. The various forms in which the food materials are stored in these different organs and tissues may now be considered. The food materials may be carbohydrates, proteins, or fats and oils (see also pp. 190-6).

I. Carbohydrates

Starch (see figs. 373-8). This is of universal occurrence in plants with the exception of fungi. As soon as sugar is formed in the leaf it is converted into starch. This starch is in the form of minute bodies without any definite structure. At night, when carbon-assimilation is in abeyance, starch is converted into sugar which travels down to the storage organs and is reconverted there into starch by the agency of leucoplasts. The starch grains deposited by the leucoplasts are much bigger in size and have a distinct, stratified appearance. Starch is insoluble in water, and is stored up as such for a longer or shorter period. When growth of the plant is taking place starch is again converted into sugar which then travels from the storage organs to the growing regions, and is eventually made use of by the protoplasm for its nutrition and growth.

Glycogen. In fungi the carbohydrate is stored in the form of glycogen. It is allied to starch and is readily converted into sugar. It is a white amorphous powder, and dissolves in hot water. It is coloured reddish brown by iodine solution.

Inulin (see fig. 372). It is a soluble carbohydrate and has the same chemical composition as starch. It is found in the underground parts of some *Compositae*, *Liliaceae* and *Amaryllidaceae*. It may be converted into some form of sugar.

Sugars. Grape-sugar is the first carbohydrate formed in the green leaves of plants. But as soon as it is formed it is usually converted into starch. It is only in a few cases such as grape, onion, etc., that grape-sugar is stored up as such. Cane-sugar occurs as reserve food in sugarcane, banana, pineapple, beet, etc. Grape contains 12-15% of glucose and sugarcane contains 15-20% of sucrose.

Hemicellulose (see fig. 361). It occurs as a thickening matter in the cell-wall of the endosperm of the date seed. It may be converted into some form of sugar by the action of the enzyme *cytase*.

II. Nitrogenous Materials

Proteins. These are the most complex and at the same time the most important substances. Proteins are the chief constituents of protoplasm and nucleus, and consist of carbon, hydrogen, oxygen, nitrogen and sometimes sulphur and phosphorus; but their exact chemical composition is not known. There are various kinds of proteins found in plants as food, and they occur in three distinct conditions, viz. as definite oval or rounded granules, known as the aleurone grains; as amorphous proteins which have got no definite shape; and as soluble proteins which occur in solution in the cell-sap. Aleurone grains (see fig. 379) occur abundantly in seeds associated with starch, as in pea, bean, etc., or with oil, as in castor. When they occur with oil they are fairly big in size. The other two kinds of proteins occur in bulbs, tubers and in other storage organs.

Amino-acids and Amines. These are much simpler nitrogenous substances than proteins, and occur in solution mostly in growing regions. Less frequently they occur in the storage tissues.

III. Fats and Oils

Fats and oils are found in all groups of plants and in almost all living cells of the plant body. In angiosperms they are specially common in seeds and fruits. When oil is in great preponderance usually very little carbohydrate is present. Similarly, when starch occurs in abundance little oil is found. Big aleurone grains often accompany fats and oils, as in castor seed. At ordinary temperature fats are solid and oils are liquid. They are not soluble in water or in alcohol (except castor oil); all of them are, however, soluble in ether, petroleum, chloroform, etc. They occur in the form of globules in the protoplasm often saturating it. They are formed from fatty acids and glycerine (see pp. 195-6).

It is known that these substances enter into the composition of protoplasm: but they undergo many chemical changes before they are utilized by the protoplasm. They are decomposed by the enzyme *lipase* into fatty acids and glycerine. By this decomposition a large amount of heat is liberated. When oily seeds germinate a considerable quantity of fatty acids may be detected in them, while glycerine disappears almost immediately. Both these substances are finally converted into sugar. Fatty acids and glycerine may also be translocated to the growing regions where these are utilized by the protoplasm. Both of them may readily pass through cell-walls.

Food Stored in the Seed. There is always a considerable amount of food stored up in the cotyledons and in the endosperm of the seed for the use of the embryo as it grows. Food materials occur there in insoluble forms and these are first digested, i.e. rendered soluble and chemically simpler under the action of specific enzymes (see next chapter), and then utilized by the growing parts of the embryo for various purposes such as nutrition and growth of the protoplasm, cell-formations, development of the embryonic parts and also for vigorous respiration. Common forms of such food materials are the following. (1) **Starch**— it is a very common form of carbohydrate stored up in the seed. Cereals such as rice, wheat, maize, oat, barley, etc., are particularly rich in starch. (2) **Hemicellulose**—it is deposited as thickened cell-walls of the endosperm of many palm seeds, e.g. date-palm, betel-nut-palm, nipa-palm, vegetable ivory-palm, etc., and also in some other seeds, e.g. coffee, mangosteen, etc. (3) **Oils**—these are deposited in most seeds to a greater or less extent. There is a special deposit of them in seeds like ground nut, gingelly, coconut, castor, safflower, etc. (4) **Proteins**—these also occur in all seeds in varying quantities. In seeds like pulses they occur in fairly high percentage. Soy bean contains 42-47% of proteins. Oily seeds also contain a high percentage of proteins, e.g. castor seed.

CHAPTER IX

DIGESTION AND ASSIMILATION OF FOOD

DIGESTION

The reserve materials are generally insoluble in water or cell-sap and also indiffusible but when translocation is necessary they are rendered soluble and diffusible by the action of enzymes. It is only in the soluble forms that food materials are absorbed by the protoplasm. *This rendering of insoluble and complex food substances into soluble and simpler forms suitable for translocation through the plant body and assimilation by the protoplasm is collectively known as* **digestion.**

The process of digestion is chiefly intra-cellular, that is, it takes place inside the cell. Extra-cellular digestion occurs in a few cases, as in the digestion of proteins by carnivorous plants, parasites, fungi, etc. In such cases the digestive agent

is secreted by the protoplasm outside the cells, where it digests or splits up the complex food materials; the products of digestion are then absorbed by the cells. Digestion, like all other physiological functions, is carried on by the protoplasm. For this purpose it secretes digestive agents known as **enzymes.**

Enzymes. Enzymes are digestive agents secreted by the protoplasm to act upon insoluble and complex foodstuff and other bodies and render them soluble. They also act upon soluble materials and split them up into simpler compounds. They are very complex organic substances (containing nitrogen) and are protein in nature. They are soluble in water, and when dry, form a white amorphous powder. They are not directly formed by the protoplasm, but at first very minute granules, known as *zymogen*, are secreted by it. The zymogen is then converted into the active enzyme, e g. pepsin from pepsinogen and trypsin from trypsinogen. Here pepsin and trypsin are the enzymes and pepsinogen and trypsinogen are the zymogens.

Properties of Enzymes. (1) The action of an enzyme is more or less specific, i.e. for a particular substance there is a particular enzyme; for instance, the enzyme that acts on starch will not act on protein or any other substance. This is expressed as 'lock and key' action; although this is the general rule there are enzymes which may act on more than one substance, and there are substances which may be acted on by more than one enzyme. (2) The enzyme is never exhausted; a small quantity of it can act on an almost unlimited supply of the substance, provided that the products of digestion are removed from the seat of its activity. (3) The enzyme acts as a catalytic agent; this means that the presence of the enzyme induces some chemical action in the substance without itself undergoing any change. Thus the enzyme may be regarded as an organic catalyst.

Kinds of Enzymes and Nature of Digestion

1. **Diastase** converts starch into dextrin and maltose.
2. **Maltase** converts maltose into glucose.
3. **Invertase** changes sucrose into glucose and fructose.
4. **Cellulase** converts cellulose into glucose.
5. **Cytase** converts hemicellulose into glucose.
6. **Inulase** changes inulin into fructose.
7. **Pepsin** changes proteins into peptones.
8. **Trypsin** transforms proteins into amino-acids.
9. **Erepsin** transforms peptones into amino-acids.
10. **Lipase** breaks up fats into fatty acids and glycerine.

ASSIMILATION

Assimilation means the incorporation of food into the body of the protoplasm. The products of digestion are taken on by the protoplasm and applied to its body. As a result of assimilation the protoplasm increases in bulk. Assimilation *is a constructive process by which the protoplasm* is continually reconstructing itself out of the nutritive substances such as sugar and simple proteins supplied to it. The various kinds of carbohydrates are converted into sugar, particularly glucose, and the various complex proteins are converted into amines and amino-acids, the simplest forms of nitrogenous food. These simplest products of digestion travel to the growing regions where the protoplasm is very active. The protoplasm then assimilates these substances into its own body. We know that the protoplasm itself is a living substance composed of very complex proteins. The food is, therefore, changed into complex protoplasmic proteins. The protoplasm, being living, it is natural to suppose that food is changed into 'live' proteins, or, in other words, food passes from non-life into life, that is, protoplasm. This is the goal of nourishment. How this mysterious change takes place we do not know. We know only this much that the protoplasm has the power of bringing about this change.

CHAPTER X

RESPIRATION AND FERMENTATION

RESPIRATION

Respiration *is essentially a process of oxidation and decomposition of organic compounds, particularly simple carbohydrates such as glucose, in the living cells with the release of energy.* The most important feature of respiration is that by this oxidative process the potential energy stored in the organic compounds in living cells is released in a stepwise manner by the action of a series of enzymes and is made available, partly at least, to the protoplasm for its manifold activities such as various synthetic processes, growth, movements, reproduction and other vital activities. In respiration the stored or *potential* energy is transformed into active or *kinetic* energy. Often a considerable amount of energy escapes from the plant body in the form of heat, as seen in *germinating seeds.* The reserve food materials that undergo oxidation are mostly simple carbohydrates, principally glucose, and sometimes also, particularly in the absence or glucose,

other substances such as complex carbohydrates, proteins and fats; these are of course first hydrolysed and then oxidized. The main facts associated with respiration are: consumption of atmospheric oxygen, oxidation and decomposition of a portion of the stored food resulting in a loss of dry weight as seen in the seeds germinating in the dark, liberation of carbon dioxide and a small quantity of water (the volume of CO_2 liberated being equal to the volume of O_2 consumed) and above all the release of energy by the breakdown of organic food. The over-all chemical reaction may be stated thus: $C_6H_{12}O_6 + 6O_2 = 6CO_2 + 6H_2O +$ Energy (sugar+oxygen = carbon dioxide+water+energy). This shows that for oxidation of one molecule of sugar six molecules of oxygen are used and that six molecules each of CO_2 and H_2O are formed. By burning sugar at a high temperature CO_2 and H_2O are also formed but in the living cells this process is carried on by a series of enzymes at a comparatively low temperature. Oxidation may be complete, as shown in the above formula, with the formation of carbon dioxide and water as end products, the former escaping from the plant body while the latter getting mixed up with the general mass of water in the cells, or, it may be incomplete with the formation of organic acids or ethyl alcohol and carbon dioxide, as represented by the equation: $C_6H_{12}O_6 = 2C_2H_5OH + 2CO_2$ (sugar = ethyl alcohol + carbon dioxide). The mere exchange of gases—oxygen and carbon dioxide—is, however, known as *breathing* and is a characteristic feature of animals. The oxygen gas, after entering through the stomata, diffuses through the intercellular spaces into the cells and slowly oxidizes not only glucose and other carbohydrates but also, less frequently though, other organic materials—like fats, proteins, organic acids and even protoplasm under extreme conditions. The carbon dioxide that is formed in respiration diffuses through the intercellular spaces and finally escapes through the stomata and the lenticels into the surrounding air; a portion of it may be retained in the cells and used for photosynthesis. In submerged aquatic plants the surrounding water containing dissolved air supplies the necessary gases for respiration and carbon-assimilation.

All the living cells of the plant, however deeply seated they may be, must respire in order to live. If the supply of air be cut off by growing the plant in an atmosphere devoid of oxygen, it soon dies. Growing organs such as the floral and vegetative buds, the germinating seeds, and the stem- and root-tips, respire actively; while adult organs do so comparatively slowly. The gases normally enter the plant through

the stomata. But these are closed at night. So, to facilitate the interchange of gases concerned, special structures are developed on the branches. These are the lenticels. Unlike the stomata they remain open. For easy diffusion of gases in the interior of the plant body, there is developed a network of air-cavities and intercellular spaces which are connected throughout and are continuous with the stomata and the lenticels (see experiment 14).

In respiration the cells are continually exhaling carbon dioxide, and in photosynthesis the green cells are continually making use of this gas during the daytime and giving off oxygen. But the latter process goes on more vigorously than the former, and practically masks it. Thus in green parts of plants the composition of the intercellular air varies, becoming much richer in oxygen during the daytime, but richer in carbon dioxide during the night. The amount of nitrogen varies but little, as this gas is not made use of by the protoplasm. Since in respiration plants are continually exhaling carbon dioxide, the atmosphere has a tendency to become richer in this gas, especially at night. Carbon dioxide is a suffocating gas, and is likely to vitiate the atmosphere. But then during the day the green plants absorb it for photosynthesis and give out oxygen which goes back to the atmosphere. The atmosphere is thus purified, and the composition of the air remains constant.

Experiment 14. Aeriferous system of the plant (fig. 409). Take a wide-mouthed bottle and a cork of appropriate size with two holes bored in it. Partially fill the bottle with water and insert the long petiole of a selected broad leaf (e.g. *Begonia*) into the water through a hole in the cork. Through the other hole introduce a bent tube with its inner end clear above the surface of water. Smear the sides of the cork, the bent tube and the petiole with paraffin-wax so that all the connexions are made air-tight. Draw out the air from the bottle through the bent tube, preferably with a vacuum pump.

Observation. As the air is pumped out a series of minute bubbles is seen to come out of the cut end of the petiole and rise upwards. Repeat the experiment after applying a coat of vaseline on the surfaces of the leaf and see that no air-bubbles appear.

Inference. This escape of air-bubbles indicates that the surrounding air is drawn into the leaf through the stomata and then it diffuses through the intercellular spaces and finally comes out through the cut end of the petiole as a

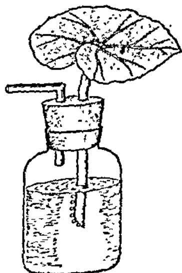


FIG. 409. Experiment on aeriferous system.

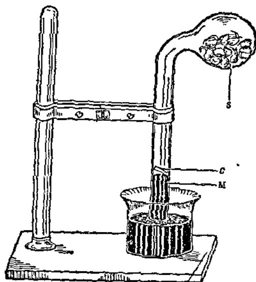
result of suction. The experiment thus proves that the intercellular spaces are in continuity with the stomata, which together constitute the aeriferous system of the plant.

Aerobic and Anaerobic Respiration (*aer*, air; *an* not; *bios*, life). Normally free oxygen is used in respiration resulting in complete oxidation of stored food and formation of carbon dioxide and water as end products; this is known as **aerobic respiration.** A considerable amount of energy is released by this process, as represented by the equation—$C_6H_{12}O_6 + 6O_2 = 6CO_2 + 6H_2O + 674$ Cal. (sugar + oxygen = carbon dioxide + water + 674 Cal. of energy). Under certain conditions, as in the absence of free oxygen, many tissues of higher plants, seeds in storage, fleshy fruits and succulent plants like cacti temporarily take to a kind of respiration, called **anaerobic respiration,** which results in incomplete oxidation of stored food and formation of carbon dioxide and ethyl alcohol, and sometimes also various organic acids such as malic, citric, oxalic, tartaric, etc. Very little energy is released by this process to maintain the activity of the protoplasm. This may be represented by the equation—$C_6H_{12}O_6 = 2C_2H_5OH + 2CO_2 + 28$ Cal. (sugar = ethyl alcohol + carbon dioxide + 28 Cal. of energy). It is otherwise known as *intramolecular respiration* because in this process intramolecular oxidation of sugar and other compounds takes place without the use of free oxygen. Anaerobic respiration may continue only for a limited period of time, at most a few days, after which death ensues, evidently due to low production of energy and accumulation of toxic substances in the cells. In certain micro-organisms (certain bacteria, yeast and some other fungi), however, the fundamental process of energy-release is anaerobic respiration. Anaerobic respiration resulting in the production of alcohol is otherwise called alcoholic fermentation.

Mechanism of Respiration. Chemical stages in respiration are not definitely known. It is, however, known that the whole process of respiration is controlled by a group of enzymes, called *respiratory* or *oxidizing enzymes*; and that it is complete in two stages: an anaerobic phase and an aerobic phase. Several reactions take place in the whole process, each reaction being controlled by a particular enzyme. At the initial (anaerobic) phase of respiration a simple sugar like glucose reacts with phosphoric acid resulting in the formation of phosphoglyceric acid. The final reaction in the first phase results in the formation of pyruvic acid. By the reactions in the first phase very little energy is made available to the cells. Pyruvic acid holds a key position in the metabolism of plant cells. Under different conditions reactions of pyruvic acid may proceed in different directions. With the access of oxygen (aerobic phase) the pyruvic acid is completely oxidized by a group of enzymes, called *oxidases*, into carbon dioxide and water. Most of the energy is released during this process. Some such enzymes have been extracted from plants and these have been seen to bring about this aerobic phase even outside the cells. Apart from these enzymes which contain iron and copper some of the vitamins and

the respiratory pigments are concerned in the process. In the absence of oxygen the pyruvic acid is incompletely oxidized into ethyl alcohol and carbon dioxide, and in *some* plants into organic acids. These changes are brought about by a group of enzymes, collectively called *zymase* (universally present in plant cells). Very little energy is made available to plant cells by this process.

***Experiment 15.* Respiration** (fig. 490). Respiration in plants can be experimentally proved in a very simple but efficient way by the following method. Appliances required for this experiment are: a flask with a bent bulb, called **respiroscope** (an ordinary long-necked flask will also do), a beaker, a suitable stand with a clamp, a quantity of mercury (according to the size of the beaker), caustic potash stick and some germinating seeds or opening flower-buds. Introduce some germinating seeds into the respiroscope. Pour a quantity of mercury into the beaker and invert the respiroscope over it. The respiroscope is fixed in this vertical position with a stand and a clamp. The air enclosed in the flask is thus cut off from the surrounding atmosphere. With the help of the forceps introduce into the respiroscope a small piece of caustic potash stick. This will float on mercury inside the respiroscope. Leave the apparatus in this position for some hours, preferably till the next day.



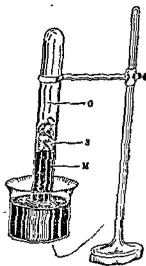


FIG. 490 FIG. 491

Experiments on Respiration. Fig. 490. Aerobic respiration. Fig. 491 Anaerobic or intramolecular respiration. *S*, seeds; *C*, caustic potash stick; *M*, mercury; *G*, gas.

Observation. It will be seen on the following day that the level of mercury in the flask has risen. It will further be seen that the volume occupied by mercury is nearly (but not actually) one-fifth the total volume of the flask.

Inference. The rise of mercury is due to partial vacuum produced inside the flask owing to the absorption of a certain volume of gas contained therein. Since caustic potash absorbs carbon dioxide we may conclude that the gas absorbed is carbon dioxide. Wherefrom has this gas come? Since atmospheric connexion has been cut off we may safely infer that this gas has been exhaled by the seeds. It is thus proved that plants give out carbon dioxide in respiration. It is to be noted that the gas, approximately four-fifths in volume, still remaining in the flask, is

almost exclusively nitrogen. As one-fifth the volume of the normal air is oxygen, we may conclude that all the oxygen originally contained in the flask has been absorbed in the process of respiration.

(**We may prove directly that oxygen is absorbed in respiration.** At the end of the above experiment dissolve some pyrogallic acid in caustic potash solution. Pyrogallate of potash is formed. The property of this chemical reagent is that it absorbs free oxygen. Now pour a quantity of pyrogallate of potash solution into the beaker over mercury, and raise the respiroscope from mercury to pyrogallate solution. *Note that the mercury in the respiroscope falls down and the pyrogallate solution enters into it.* Mark its level. Wait for some hours or overnight See then if the level rises further, very likely it does not, or does so very slightly Naturally there is no oxygen in the flask, or very little of it, as otherwise pyrogallate solution would have absorbed it and risen. Where then is the oxygen originally present in the flask (as we know one-fifth the volume of air is oxygen) gone? The only inference is that it has been absorbed by the seeds Thus it is proved definitely that in respiration oxygen is taken in and carbon dioxide is given out.)

NOTE. The experiment may be carried on in a still simpler way. Instead of mercury, caustic soda or caustic potash solution may be poured into the beaker, and the flask or respiroscope with germinating seeds inverted over it. Subsequently rise of caustic solution is noticed in the flask or the respiroscope.

Experiment 16. Anaerobic respiration (fig. 491). Completely fill a short narrow test-tube with mercury (*M*), close it with the thumb and invert it over mercury contained in a beaker. Keep the tube in a vertical position with a suitable stand. Take some germinating seeds, and remove the seed-coat from them to get rid of the enclosed air (oxygen). With the help of the forceps hold the skinned seeds under the test-tube, and release them one after another. As soon as released the seeds rise to the closed end of the tube. Introduce in this way five or six seeds. They are now free from oxygen Prior to their introduction it is better to soak the seeds in distilled water, or to introduce into the test-tube a small quantity of distilled water with the help of a bent tube. This keeps the seeds moist. *Note on the following day that the mercury column has been pushed down,* owing to the exhalation of a gas (*G*) by the seeds. Within one or two days nearly the whole of the mercury is seen to be pushed out of the tube. Introduce a small piece of caustic potash stick into the test-tube with the help of the forceps. It floats on mercury, and coming in contact with the gas, absorbs it quickly. The mercury rises again and fills up the test-tube. The gas evidently is carbon dioxide.

Respiration is a destructive Process. It is a destructive process and consists in the decomposition of some of the food materials, more particularly the simple carbohydrates, and *this decomposition is brought about by the action of specific* enzymes secreted by the protoplasm; nevertheless, it is highly beneficial to the life of the plant for the reason that respiration sets free *energy* by which work is performed. This energy is absolutely necessary for the various synthetic processes, growth, movements, etc. If we think of the enormous development of a large tree we can at once realize what a vast amount of energy has been utilized in constructing that body. A considerable amount of energy, of course, escapes from the plant body in the form of heat. During vigorous respiration heat is generated. A thermometer thrust into a mass of

germinating seeds will show a marked rise of temperature (see experiment 17). This production of heat is an easily observed form of energy. Respiration results in a loss of dry weight of the plant. This is believed to be due to escape of carbon dioxide.

Experiment 17. Heat generated in respiration (fig. 492). Take two thermoflasks, and fill one (*A*) of them with germinating seeds and the other (*B*) with the same killed by boiling for a few minutes and then soaked in 5% formalin to prevent any fermentation in the flask generating heat. Insert a sensitive thermometer in each as shown in the figure and pack the mouth of the flask with cotton. It is better to place, half immersed in seeds, a small test-tube containing a small piece of caustic potash stick. Wait for some time and note a remarkable rise of temperature in the case of flask *A* containing germinating seeds; while the flask *B* containing killed seeds shows no rise of temperature. This evidently proves that heat is evolved in respiration.

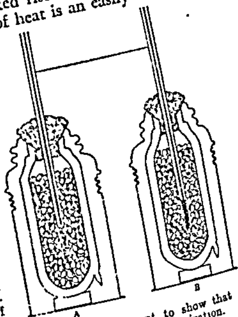


FIG. 492. Experiment to show that heat is generated in respiration.

Conditions affecting Respiration

1. **Oxygen.** Presence of oxygen is the first and the most essential condition for respiration since this is an *oxidation* process. The intensity of the process is markedly affected by alteration in the concentration of oxygen in the surrounding air. If the concentration goes below 5 per cent the process rapidly falls off. With gradual increase, however, in oxygen concentration up to even 100 per cent there is a corresponding steady rapidity in the process.

2. **Temperature.** It affects markedly the rate of respiration. The minimum rate is reached at 0°C. or even at 10°C. With the rise of temperature the rate increases and the maximum is reached at 45°C. or even at 40°C. Beyond this point protoplasm is injured and respiration decreases in rate. The optimum temperature, however, lies between 30°C. and 35°C.

3. **Light.** The effect of light is only indirect; in bright sunlight the respiratory activity is greater than in subdued light. This may be due to the fact that in bright light stomata remain wide open and oxygen is easily and quickly absorbed.

4. **Supply of Water.** Protoplasm saturated with water respires more vigorously than that in a desiccated condition.

as in the dry seed. For this reason the rate of respiration increases with the supply of water.

5. **Vitality of Cells.** Respiration in young active cells is more rapid than in old cells. Vegetative buds, floral buds and germinating seeds respire more vigorously than older parts of the plant body.

6. **Carbon Dioxide Concentration.** If, as a result of respiration, carbon dioxide be allowed to accumulate around the plant respiration slows down and comes to a standstill. If this carbon dioxide is removed, respiration again goes on normally.

7. **Nutritive Materials.** Food materials, more particularly soluble carbohydrates, affect respiration to a considerable extent. With the supply of oxygen these materials become quickly broken down.

Respiratory Quotient (R.Q.). There is a relation between the volume of carbon dioxide evolved and the volume of oxygen consumed in the process of respiration, and the ratio of these two volumes is known as respiratory quotient. Thus when sugars are consumed in respiration, as mostly in the cereals, the respiratory quotient (R.Q.), i.e. the ratio of $CO_2 : O_2$ is equal to unity. This means that for one molecule of CO_2 given out one molecule of O_2 is used. Sugars are by no means the only compounds consumed in respiration. Fats, proteins, organic acids and other materials are also consumed in the process, and the R.Q. in such cases may vary greatly from unity. When fats are consumed in respiration, as in the oily seeds, the R.Q., i.e. the ratio of $CO_2 : O_2$ is less than unity. Fats are poorer in oxygen than are the sugars and, therefore, correspondingly more oxygen is required for combustion of fats, or, in other words, less CO_2 is evolved for a particular volume of O_2 taken up. Likewise, when proteins are used in respiration, the R.Q. is less than unity since the proportion of oxygen to carbon in them is less than in carbohydrates. When organic acids are oxidized the R.Q. is found to be more than unity; such compounds are relatively rich in oxygen in comparison with carbohydrates. At night succulent plants such as cacti absorb oxygen without giving out carbon dioxide; in them instead of carbon dioxide organic acids (malic, citric, oxalic, etc.) are formed as a result of incomplete oxidation of sugar. During the daytime, however, they give out CO_2. The concept of respiratory quotient is important because it serves as a clue to the nature of compounds used in respiration.

Respiration and Photosynthesis

1. In respiration plants utilize oxygen and give out carbon dioxide, while in photosynthesis plants utilize carbon dioxide and give out oxygen; that is, one process is just the reverse of the other.

2. Respiration is a destructive (catabolic) process, but photosynthesis is a constructive (anabolic) process. In the former process sugar is broken down into CO_2 and H_2O with the liberation of energy, while in the latter process CO_2 and

H_2O combine into sugar with the storage of energy. Respiration is thus a *breaking-down* process, and photosynthesis a *building-up* process.

3. The intermediate chemical reactions in the breakdown of sugar in respiration and those in the synthesis of sugar in photosynthesis are much the same. In both the processes phosphoglyceric acid is formed representing an intermediate product.

4. Respiration is carried on by all the living cells of the plant at all times, i.e. it is independent of light and chlorophyll; while photosynthesis is carried on only by the green cells, and that, too, only in the presence of sunlight. Although photosynthesis persists only for a limited period, this process is much more vigorous than respiration.

5. Respiration results in a loss of dry weight of the plant due to breaking-down of food materials and the formation of carbon dioxide which escapes from the plant body; but photosynthesis results in a gain in dry weight due to formation of sugar, starch, etc., which accumulate in the plant body.

FERMENTATION

Fermentation is the incomplete oxidation of sugar into alcohol and carbon dioxide brought about by certain microorganisms in the absence of oxygen. The change is due to the action of an enzyme, known as *zymase*, secreted by the micro-organisms, and not due to their direct action on sugar. Fermentation is most readily seen in toddy and also in grape-juice, where sugar is broken up by unicellular yeast plants into alcohol and carbon dioxide, the frothing in the case of toddy being due to the formation of this gas. Fermentation may be defined as an enzyme action on sugar in the absence of free oxygen, splitting it (sugar) into carbon dioxide and alcohol and sometimes organic acids. The process is analogous to anaerobic respiration and may be represented by identical formula—$C_6H_{12}O_6$ + Zymase = $2C_2H_6O$ + $2CO_2$ + Zymase + Energy (sugar + zymase = alcohol + carbon dioxide + zymase + energy). Common examples of fermentation are: alcoholic fermentation (conversion of sugar into alcohol by yeast), lactic acid fermentation (souring of milk), butyric acid fermentation (rancidity of butter), acetic acid fermentation (manufacture of vinegar from alcohol), etc.

Experiment 18. Fermentation. Experiment on fermentation may be easily carried out with the help of a Kuhne's fermentation vessel (fig. 493) and the procedure is as follows. Prepare a 5% glucose solution in water and add to it a small quantity of fresh brewers' yeast, or collect a quantity of date-palm juice early in the morning. Completely fill the closed upright tube of the fermentation vessel with this solution or the juice and partially fill the side-tube up to or below the base of the bulb. Warm the solution to about 25°C. *and leave the apparatus in a warm place for a few* hours. It will be seen that a gas collects at the upper end of the closed tube displacing the solution which now accumulates in the bulb of the side-tube and overflows it The evolution of gas continues so long as the sugar in the solution is not exhausted. Then introduce a small piece of caustic potash stick into the fermentation vessel and gently shake it to dissolve the piece, taking care that the gas collected in the closed tube does not escape Place the fermentation vessel again in the vertical position. Within a few minutes it will be seen that the gas is absorbed by the solution which rises and again fills up the tube The gas evidently is carbon dioxide evolved during fermentation.

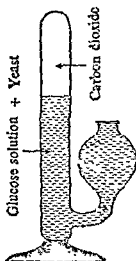


FIG. 493 Experiment on fermentation with Kuhne's fermentation vessel.

Respiration and Fermentation

Both respiration and fermentation are oxidation processes by which energy stored up in carbohydrates and other compounds is set free, and carbon dioxide given out. The two processes depend upon whether free oxygen is available or not, and to what extent oxidation (complete or incomplete) proceeds. Recent researches show that respiration in higher plants takes place in two stages: an anaerobic phase resulting in incomplete oxidation of sugar, and an aerobic phase resulting in complete oxidation of the intermediate products formed in anaerobic respiration, into carbon dioxide and water. Fermentation is that type of anaerobic respiration in *which alcohol is produced (Palladin). Generally* speaking, respiration includes only aerobic respiration; while fermentation is regarded as a synonym for anaerobic respiration. On this basis the distinctions between respiration and fermentation are as follows:

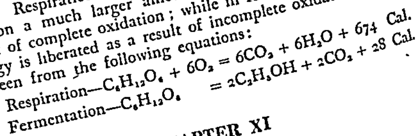
1. Respiration takes place in the presence of free oxygen; while fermentation takes place in the absence of free oxygen which is derived from rearrangement of molecules of some carbohydrates, and thus fermentation is also known as intramolecular respiration.

2. Respiration takes place in all the living cells of the plant body and at all times in the presence of carbohydrates;

while fermentation takes place only in the presence of some easily available carbohydrates such as different sugars under the action of certain micro-organisms such as yeast, bacteria, fungi, etc.

3. In respiration carbohydrates are completely oxidized into carbon dioxide and water; while in fermentation carbohydrates are incompletely oxidized forming carbon dioxide, alcohol and various other products.

4. Respiration is more efficient than fermentation; in respiration a much larger amount of energy is liberated as a result of complete oxidation; while in fermentation much less energy is liberated as a result of incomplete oxidation as may be seen from the following equations:



Respiration—$C_6H_{12}O_6 + 6O_2 = 6CO_2 + 6H_2O + 674$ Cal.

Fermentation—$C_6H_{12}O_6 = 2C_2H_5OH + 2CO_2 + 28$ Cal.

CHAPTER XI

METABOLISM

Two series of chemical changes or processes are simultaneously going on in a plant cell, one leading finally to the construction or building-up of the protoplasm, and the other to its decomposition or breaking-down. These processes which are constructive on the one hand and destructive on the other are together known as **metabolism**. Metabolism takes place only in the living cells, and is one of the characteristic signs of life. The processes that lead to the construction of various food materials and other organic compounds and finally of protoplasm are together known as **anabolism**, and those pro[cut off] cesses leading to their destruction or breaking-down [cut off] **catabolism.**

Anabolism. The main anabolic or constructive changes are: formation of sugars and other carbohydrates, formation of proteins, and formation of fats and oils. These changes or processes are regarded as anabolic because the protoplasm continually reconstructs itself with these nutritive substances. By anabolism a considerable amount of potential energy is stored in those substances for future use of the protoplasm.

Catabolism. Side by side with anabolism, catabolic or destructive changes or processes are also going on in the living cells of the plant body. The main catabolic or destructive processes are: digestion, respiration and fermentation. By

these processes complex food substances are gradually broken down into simpler products, e.g. various carbohydrates into glucose, various proteins into amines and amino-acids, and fats and oils into fatty acids and glycerine. The potential energy already stored up in them is released by catabolism into kinetic energy for manifold activities of the protoplasm. Carbon dioxide and water are formed as a result of complete oxidation of glucose in aerobic respiration, and alcohols and organic acids as a result of incomplete oxidation of glucose in anaerobic respiration or fermentation. Amino-acids sometimes result from the decomposition of protoplasm. Besides, the secretory products such as enzymes, vitamins, hormones, cellulose, nectar, etc., are also the results of catabolic processes. Catabolism also results in the formation of many *by-products* in plants. The various waste-products such as tannins, essential oils, gums, resins, etc., belong to this category. These being useless to the protoplasm or even deleterious are removed from the sphere of protoplasmic activity, and mostly stored up in special cells, bark, old leaves, heart-wood and glands. In this sense the various kinds of waste products may also be regarded as excretions or excretory products.

By-products of Metabolism. During metabolism many substances are formed which are not directly connected with the activity of the protoplasm. These are known as *by-products*. The various waste products (see pp. 197-202) belong to this category. There are a few others also which, although of no value to the plant for its nutrition, yet play some useful parts in other directions. These are some of the vegetable (organic) acids, the aromatic substances, lignin and cutin (modifications of cellulose) and some of the colouring matters (decomposition products of chlorophyll).

Excretions. Lastly, mention can be made of the excretions or excretory products. These are substances which are not of any use to the protoplasm ; so they are removed from the seat of protoplasmic activity and deposited mostly in dead cells. Typical excretory products are carbon dioxide and water. The various kinds of waste products may also be regarded as excretions in the sense that these are mostly removed from the body of the protoplasm, i.e. the seat of vital activity.

CHAPTER XII

GROWTH

The growth of a plant is associated with both constructive and destructive changes. The former lead to the formation of various nutritive substances and the protoplasm, and the latter to their break-down. The protoplasm assimilates these nutritive substances and increases in bulk ; as it increases it secretes cellulose and other products which are directly responsible for the building up of the plant body. The cells divide and numerous new cells are formed : these increase in size and become fully turgid, and the plant grows as a whole. Growth is thus a vital phenomenon brought about by the protoplasm. *It may be defined as a permanent and irreversible increa[illegible] in size and form attended by an increase in weight* ; sometimes at an early stage of growth a loss in weight is noticed; as, for example, when a potato tuber sprouts it shows a loss of weight in the beginning due to transpiration and respiration. But that is soon made good [illegible] formed by the sprouting shoot. [illegible] lants, and is difficult to detect a [illegible] short space of time without the help of a suitable instrument. There are certain plants which, however, show very rapid growth, but it is confined to certain organs only ; as, for instance, it is seen that the stamens of wheat, young shoots of certain bamboos and tendrils of some *Cucurbita* show an average growth in length of about 1 mm. per minute. The growth of a plant, however slow it may be, can be accurately measured with the help of an instrument, called the **auxanometer.**

Experiment 19. Growth in Length of the Shoot. The *auxanometer* is an instrument by means of which a small increase in *length* can be magnified many times. From this total known magnification recorded by the auxanometer the actual length attained by a plant *within* a certain specified time can be easily calculated. Two types of auxanometer are in common use; the first and the simplest type is the **lever auxanometer** or **arc indicator** (fig. 494), and the second is the **pulley auxanometer** or simply called **auxanometer** (fig. 495). In both the principle is the same.

(a) In the **lever type** there is a movable lever or indicator fixed to a wheel round which passes a cord. One *end of* the cord is tied round or gummed to the apex of the stem, and from the other end a *small* weight is suspended to keep the cord taut. As the stem increases *in* length the wheel slowly rotates under the weight suspended and the indicator *moves* down the graduated arc. The growth in length of the plant is *thus recorded* by the instrument on a magnified scale. From the *record thus* obtained *the* actual increase in length of the stem is calculated; for instance, if the *lever* has traversed a distance of 45 cm. in 24 hours, and the *magnification* is

90 times, the actual growth in the same period is $\frac{45}{90}$ cm., i.e., ·5 cm. or 5 mm. and, therefore, in 1 hour the actual growth of the plant is $\frac{5}{24}$ mm., i.e. ·2 mm.

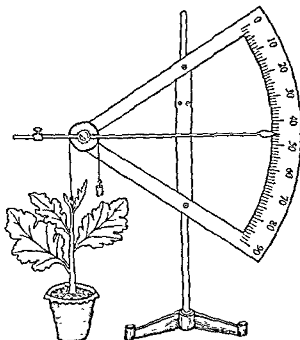


Fig. 494. Arc indicator or lever auxanometer.

(b) With the **pulley auxanometer** a permanent record of growth within a specified time is obtained on a smoked paper which is wrapped round a drum or cylinder. The drum is rotated by means of a clock-work mechanism. A cord with one end attached to the plant is passed round a small wheel, and a small weight suspended from the other end. Round the bigger wheel, which is fixed to the smaller one, passes another cord with two small weights at the two ends. There is a horizontal pointer attached to the cord with the tip *in contact with the smoked paper.* As growth takes place and the drum rotates, the pointer, being attached to the cord of the bigger wheel, leaves a mark on the paper on a magnified scale. After a period of growth the paper is removed and dipped into varnish, and the smoke or soot becomes fixed on the paper. A staircase curve may be traced on the paper indicating intermittent growth, the horizontal portion signifying cessation of growth and the diagonal portion the actual growth; duration of growth is also indicated. If growth proceeds continually a diagonal curve is traced on the paper instead of a starcase one. Magnifica-

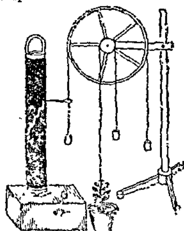


Fig. 495. A pulley auxanometer.

tion being known it is easy to calculate the actual growth within a certain specified time.

Crescograph. The late Sir Jagadis C. Bose constructed a very delicate apparatus known as crescograph which is an electric device. With the help of this apparatus the growth of a plant can be magnified one thousand to ten thousand times and accurately measured. At this high magnification it has been found possible to measure the progress of growth even in seconds.

Conditions necessary for Growth. Since growth is brought about by the protoplasm the conditions necessary for growth are the same as those that maintain the activity of the protoplasm. These are as follows:

1. **Supply of Nutritive Materials.** Growth can only take place when the protoplasm of the growing region is supplied with nutritive materials. The protoplasm assimilates these materials and finally secretes cellulose and other products which make up the skeleton of the plant. Food materials are also necessary because they supply the *potential* energy.

2. **Supply of Water.** An adequate supply of water is absolutely necessary to maintain the turgidity of the growing cells. Turgidity is the first step towards growth The protoplasm can only work when it is saturated with water. An abundant supply of water makes good the loss due to *transpiration*. It is, however, a fact that only a small quantity is required for actual growth.

3. **Supply of Oxygen.** Supply of free oxygen is indispensable for respiration of all living cells. Respiration is an oxidation process by which the *potential* energy stored in the food is released in the form of *kinetic* energy and made use of by the protoplasm for its manifold activities.

4. **Suitable Temperature.** The protoplasm requires a suitable temperature for its activities; it ceases to carry on its functions or does so very slowly at a low temperature; while a temperature of 45° to 50°C. coagulates and kills the protoplasm. A healthy condition of the protoplasm is maintained within certain degrees of temperature. This is said to be due to the thermotonic effect of temperature. The optimum temperature ordinarily averages from 28° to 30°C., and the minimum lies somewhere at 4°C.

5. **Light.** Light is not absolutely necessary for the initial stages of growth. In fact, plants grow more rapidly in the dark than in the light. Although light has a retarding effect on growth, a healthy condition of the protoplasm is maintained and the plant becomes sturdy when there is a certain intensity of light. Moreover, as we have already learnt, stomata remain

open and chloroplasts function preparing food substances only in the presence of light. All this is said to be due to the **phototonic** or stimulating effect of light. Continued absence of light is very harmful to plants. Plants grown in the dark have soft, long, weak and slender stems, and are pale-green or pale-yellow in colour and sickly in appearance (etiolated). Such plants seldom produce flowers and fruits. In the absence of light many plants remain underdeveloped. The relative length of day and night has a profound influence on the development of flowers and fruits (see photoperiodism, p. 349). The effect of particular rays of light on the growth of the plant can be easily seen when a pot plant is grown within a double-walled bell-jar which has been filled up with red, yellow, green or any other solution (see also p. 318). The effect of unilateral light on growth and movements is discussed on pp. 351 and 355.

6. **Force of Gravity.** This factor determines the direction of growth of particular organs of the plant body (see p. 355). The root grows towards the force of gravity, and the stem away from it.

Phases of Growth (fig. 497). Growth does not take place throughout the whole length of the plant body, but it is localized in special regions called *meristems* which may be apical, lateral, or intercalary. The growth in length is due to gradual enlargement and elongation of the cells of the apical meristems (root-apex and stem-apex) and in dicotyledons and gymnosperms the growth in thickness is due to the activity of the lateral meristems, that is fascicular cambium, interfascicular cambium and cork-cambium. If the history of growth of any organ of a plant be followed three phases can be recognized in it.

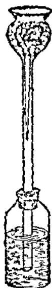
1. **The Formative Phase.** It is restricted to the apical meristem of the root and the stem. The cells of this region are constantly dividing and multiplying in number. They are characterized by abundant protoplasm, a large nucleus and thin cellulose wall.

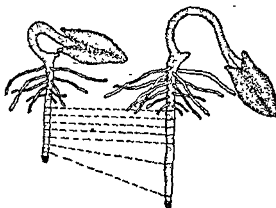
2. **The Phase of Elongation.** It lies immediately behind the formative phase. The cells no longer divide in this phase, but they increase in size; they begin to enlarge and elongate until they reach their maximum dimension. In the root this phase occupies a length of a few millimetres, and in the stem a few centimetres. In some of the climbers it may occupy a much longer space than this.

3. **The Phase of Maturation.** This phase lies further back.

Here the cells have already reached their permanent size; the thickening of the cell-wall takes place in this phase.

Grand Period of Growth. Every organ of the plant body, in fact every cell that the organ is composed of, shows a variation in the rate of its growth. The growth is at first slow, then it accelerates until a maximum is attained, then it falls off [illegible] slows down until it comes to a [illegible] organ or a cell or the plant as a whole [illegible] whole period is called the grand period of growth. Within the grand period variations in growth occur due to external and other causes. There is thus the *diurnal variation of growth*. Light inhibits growth, and too intense light even checks it altogether. Thus plants grow quicker during the night than during the day. During the night the retarding or inhibiting action of light is removed, and the rate of growth of a plant gradually increases until dawn, while during the day the rate of growth gradually decreases until about sunset. There is also *seasonal variation of growth*; during winter the growth of many plants is checked or becomes very slow, but during spring growth proceeds rapidly.





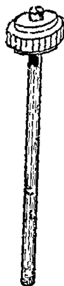


FIG 496 FIG. 497 FIG. 498

Fig. 496. Measurement of growth of root. Fig. 497. Phases of growth of root. Fig. 498. A space marker wheel.

Experiment 20. Distribution and Rate of Growth. (*a*) **Root.** With the help of a *space marker wheel* (fig. 498) mark the root of a germinating seed with transverse lines equidistant from each other. Waterproof Indian ink should be used for the purpose. The germinating seed is then packed in wet cotton and placed in the bulb of a thistle funnel which is allowed to

stand in a bottle containing water. The stem of the funnel is covered with black paper to prevent curvature of the root owing to light. After a few days it is seen that the lines at a little distance behind the tip become widely separated from each other, while those higher up and at the tip remain more or less intact. This evidently shows that the growth is fastest behind apex. The *rate of growth* may easily be measured from day to day with the help of a scale. (b) **Stem.** The distribution of growth in the stem is also found out in a similar way. For this the thistle funnel need not be used. The stem shows the same phases of growth as the root. The rate of growth of the stem may be accurately measured with the help of an auxanometer (see figs. 494-5).

Hormones. It is now definitely known that certain synthetic products formed in very minute quantities as a result of metabolism inside the plant body have a profound influence on the *growth* of the plant organs and on the various kinds of *tropic movements* exhibited by such organs; they also have a marked effect on certain physiological processes. These are known as the **hormones.** They are formed in one part of the plant body, chiefly in the apical meristem, and transported from there to another part to produce a particular physiological effect there. The presence of hormones was first demonstrated by experimental method. It has now been possible to extract them from plants by appropriate chemical methods. At low concentration they stimulate growth, while at high concentration they retard growth. Various kinds of hormones have been discovered till now. Of them auxins and heteroauxin (indole-acetic acid, first obtained from human urine) are well known. A few more have been lately added. Heteroauxin causes the formation of roots in stem-cuttings and in grafting. Auxins are responsible for seed germination, seedling-growth and growth of plant organs; they also stimulate cell-divisions in the meristematic tissue, and influence certain physiological processes; besides, the rôle of hormones in tropic responses has now been well established. Thus *phototropism* and *geotropism* are now explained on hormonal basis. In the case of phototropism hormones in course of their downward movement from the apex accumulate in the shaded side which then grows more rapidly than the illuminated side, and thus a phototropic curvature takes place, i.e. the shoot bends towards the light. In the case of geotropism hormones accumulate on the lower side of the horizontally placed shoot. Thus the growth of this side is stimulated, and the stem bends upwards. In the horizontally placed root hormones similarly accumulate on the lower side but the root reacts in a different way. It is probable that the growth of the root is stimulated by lower concentration of the hormones. Therefore, the particular concentration that has stimulated the growth of the stem checks the growth of the root on its lower side. As a consequence the root bends downwards. Hormones responsible for the development of the root, stem, leaf, flower, fruit, etc., have also been discovered.

Vernalization and Photoperiodism. The influence of temperature and of day-length on the sexual reproduction of plants, particularly in the case of annuals and biennials, has been lately investigated. The outcome of these investigations is the discovery of very important phenomena known as vernalization and photoperiodism. It is interesting to note that some plants, mostly of the temperate regions, require a period of low temperature before flowering takes place. But for this condition the plants will not produce flowers. In fact, if the low temperature requirement (1° to 10°C.) of the plants be artificially supplied to the soaked seeds undergoing germination, it is seen that the plants flower much earlier. This method of inducing earlier flowering by pre-treatment of the seeds with very low temperature was developed in Russia by Lysenko and is known as vernalization. Practical benefits derived from this method are to induce earlier flowering and earlier maturing of the crop, to escape frost, drought and flood, and to extend cultivation to regions with very low temperature. Thus this method has helped the Russian farmers to grow crops in Siberia where for the ten months in the year the soil remains ice-bound and unfit for any

kind of cultivation; during the remaining two months only the early maturing crops could be grown.

The influence of day length on reproduction was studied in America by Garner and Allard. According to them some plants require day-length longer than 12 hours for flowering and others less than 12 hours for this purpose. The former are known as long-day plants and the latter short-day plants. There are also some plants which are day-neutral as they flower at any day-length. The relation of the time of flowering to the daily length of the period of illumination is known as **photoperiodism**. Photoperiodism has helped in the control of flowering of a large number of agricultural and horticultural plants. Artificial shortening of day-length by *shading*, or lengthening of the day-length by electric illumination has induced plants to flower earlier than the normal ones. By reducing the day-length by *shading* Dr. S. M. Sircar of Calcutta University has been able to induce flowering of a winter variety (AMAN) of rice in 50 days against the normal flowering in 140 days. The phenomenon of photoperiodism is of considerable practical importance in growing plants at seasons where the required day-length is not available under natural conditions. Flowering of various annual and biennial plants at different seasons of the year is mainly due to the seasonal day-length. In agricultural research this is of particular benefit as by artificial control of day-length (daily illumination) two crop varieties which normally flower at different seasons can be made to *flower simultaneously* so that cross-pollination for the purpose of crop-improvement can be effected.

CHAPTER XIII

MOVEMENTS

Living beings are distinguished from non-living ones by their power of movement. Protoplasm is sensitive to various external agencies which act as stimuli such as heat, light, electricity, gravity, certain chemicals, etc., and plants or plant organs often respond to such stimuli by movement of their body in a particular direction taking up thereby a convenient position. The capacity of plants or their particular organs to receive stimuli from without and to respond to them is spoken of as **irritability**. Irritability expresses itself in some kind of movement and is a decided advantage to the plant since by this movement it can adjust itself according to the conditions of the environment.

Conditions necessary for Movements. (1) **Water.** An adequate supply of water to the organs concerned is essential for certain kinds of movements; a turgid condition of the cells is indispensable for the purpose. (2) **Temperature.** Movement can only occur within a certain range of temperature. (3) **Oxygen.** A steady supply of air (oxygen) is necessary for respiration of the living cells of the organs concerned. Respiration releases energy for work. (4) **Hormones.** Hormones (see p. 349) are now known to have a profound influence on growth and certain kinds of movement. (5) **Non-fatigue.**

Continued stimulation brings about fatigue. No response is evoked by a fatigued organ or tissue.

Kinds of Movements. Plants show different kinds of movements, and these may be broadly classified as (I) movements of locomotion and (II) movements of curvature.

I. Movements of Locomotion

Movements of protoplasm within the cell, free movements of naked masses of protoplasm and those of uncellular or multicellular organs and entire organisms are expressed as movements of locomotion. These movements may again be (A) spontaneous (or autonomic) and (B) induced (or paratonic).

A. Spontaneous Movements. The spontaneous movement is the movement of the protoplasm or minute free organs or entire organisms *of their own accord*, that is, without the influence of external factors ; it may be due to some internal causes, not clearly understood. Common instances are: ciliary movement of free ciliated protoplasmic bodies ; amoeboid movement of free non-ciliated protoplasmic masses ; rotation or circulation of protoplasm within the cell ; oscillating movement of *Oscillatoria* (see fig. 526) ; and brisk movements of many unicellular algae like desmids and diatoms, as seen under a microscope.

B. Induced Movements. Movements of minute free organs or entire organisms—unicellular or multicellular—may be induced by some external factors which may be in the nature of *certain chemical substances, light and heat. These factors act* as stimuli. Movements thus influenced by external stimuli are otherwise called **taxisms**, or tactic movements, and depending on the nature of the stimulus taxisms may be (1) chemotaxis when influenced by chemical substances, (2) phototaxis when influenced by light, and (3) thermotaxis when influenced by temperature.

1. **Chemotaxis.** Chemotaxis is the movement of free organs or organisms brought about by the presence of certain chemical substances. There are certain bacteria which are strongly attracted by the presence of free oxygen ; they move towards the source of supply. Chemotaxis is best exhibited by the male reproductive cells (antherozoids) of many 'flowerless' plants. Thus in mosses cane-sugar is secreted by the archegonium for the purpose of attracting the antherozoids towards it. In ferns malic acid is secreted for the same purpose.

2. **Phototaxis.** Phototaxis is similarly the movement of

free organs or organisms in response to the stimulation of light. Algae afford very good examples of phototaxis. They move towards the source of weak light being attracted by it. Very strong light, however, repels them ; they turn away from it. Another striking example of phototaxis is afforded by the chloroplasts of the leaf. Too intense light decomposes chlorophyll and, therefore, under this condition the chloroplasts arrange themselves one over the other alongside the lateral walls of the palisade cells of the leaf. This arrangement or movement of the chloroplasts is called **apostrophe.** In subdued light, however, they arrange themselves along the outer and inner walls. This arrangement or movement of the chloroplasts is called **epistrophe.**

3. **Thermotaxis.** Thermotaxis is similarly the movement of free organs or organisms in response to the stimulation of heat. If there is a difference in temperature they are seen to move towards the warmer side. Protoplasm shows more rapid rotation or circulation if the tissue be gently warmed. Thus if a section from a *Vallisneria* leaf be slightly warmed over a burning match-stick and then examined under the microscope the protoplasm is seen to rotate more rapidly.

II. Movements of Curvature.

Higher plants being fixed to the ground are incapable of any locomotion. Some of their organs, however, show different kinds of movement. Thus these organs may move and change their position or direction by means of curvature. As these organs move they take up an advantageous position to carry on their functions more effectively. Movements of curvature may be mechanical or vital. The latter may again be spontaneous (or autonomic) and induced (or paratonic).

A. **Mechanical Movements.** Mechanical movements are exhibited by certain non-living organs of plants, e.g. bursting of explosive fruits (see p. 167), bursting of sporangia of ferns (see fig. 659) and some other structures. Some fruits burst suddenly when they dry up, e.g. *Phlox*—a garden herb, *Barleria* (B. JHANTI ; H. VAJRADANTI), camel's foot climber (*Bauhinia vahlii*; B. LATA-KANCHAN; H. CHAMBULI—see fig. 343). *Andrographis* (B. & H. KALMEGH OR MAHATITA), etc., and others do the same when they absorb water, e.g. *Ruellia* (see fig. 342). The dry long awn of certain grasses—wild oat, for example, coming in contact with water begins to twist and roll. The elaters of *Equisetum* spore are very hygroscopic ; when the air is moist they roll up spirally round the spore, and when the air is dry they uncoil and stand out stiffly from the spore (see fig. 670).

Mechanical movements of this nature having a definite relation with moisture (by imbibition or by loss of it) are otherwise known as *hygroscopic* movements.

B. Spontaneous Movements. Spontaneous movements are movements of plant organs *of their own accord*, that is, without the influence of external factors. Such movements may be of two kinds: (1) movement of variation and (2) movement of growth.

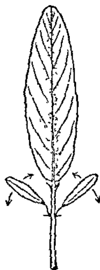


FIG. 499. Indian telegraph plant (*Desmodium gyrans*) showing spontaneous movement of the two lateral leaflets.

1. Movement of Variation. The movement of variation is the movement of *mature* organs due to *variation in turgidity* of the cells making up those organs. It is somewhat rapid. The spontaneous movement of variation is rather rare; in the majority of plants the movement of cellular organs is induced by external factors. The spontaneous movement is, however, very remarkably exhibited by the *pulsation*, i.e. rising and falling of the two lateral leaflets of Indian telegraph plant (*Desmodium gyrans*; B. BAN-CHANDAL; H. BAN-CHAL—fig. 499), the terminal leaflet, however, remaining fixed in its position. Normally these two leaflets move up and down from morning till evening, i.e. so long as sunlight is available; but sometimes these continue to move till late hours at night depending on the energy that they have conserved from the sunlight during the daytime.

Turgor Movements. These are movements exhibited by certain plant organs due to changes in the turgidity of certain cells of those organs, commonly the pulvinus in the case of the leaf. Turgor movements are often rapid and may occur again and again. These may be spontaneous (movement of variation), as exhibited by Indian telegraph plant, or may be induced by contact, light, heat, etc., as exhibited by sensitive plant (see fig. 505), sensitive wood sorrel (see fig. 504), *Averrhoa* (B. KAMRANGA; H. KAMRAKH), most species of *Leguminosae*, some species of wood-sorrel (*Oxalis*), and by the opening and closing of the stomata

2. Movement of Growth. The movement of growth is the movement of *growing* organs *due to unequal growth* on different sides of those organs. It is very slow. This kind of movement is seen in some trailers and creepers. In them at one time the growth is comparatively rapid on one side of the stem and then it passes on to the opposite side. The stem tip then moves from one side to the other. In such a case the stem, as it elongates, moves in a zigzag course. The movement

of this kind is known as (1) **nutation.** If the growth pass regularly around the stem, it then moves in such a way as form a spiral, as in tendrils and twiners. The movement this kind is said to be (2) **circumnutation.** Another kind growth movement is exhibited by most of the young leaves. them at the initial stage the growth is more rapid on the undersurface and, therefore, they remain rolled or folded o the upper surface. This kind of growth movement is calle (3) **hyponasty.** Later due to more rapid growth on the uppe surface the leaves open and become flat and straight. This i called (4) **epinasty.** A striking example is afforded by fern leaves (see fig. 656). Here the leaves are at first closely coiled due to hyponastic growth, and later they uncoil and become straight due to epinastic growth.

C. Induced Momements. Movements of plant organs may be induced by external factors which act as stimuli. The stimuli may be in the nature of (1) contact, (2) light, (3) gravity, (4) temperature, (5) certain chemical substances, and (6) moisture. Induced movements are broadly of two kinds: (a) tropic and (b) nastic.

(a) **Tropic Movements or Tropisms.** Tropic movements of plant organs are, like taxisms, always directive, i e. the direction of movement is determined by the direction from which the stimulus is applied, and the organs move either towards the source of the stimulus or away from it. The nature of the stimuli such as (1) contact, (2) light, etc., as stated above, and the corresponding tropic movements are as follows:

1. **Contact with a Foreign Body.** The movement of an organ stimulated by contact with a foreign body is called **haptotropism.** Twining stems and tendrils are good examples illustrating haptotropism. These organs are sensitive to contact with a foreign body but the reaction is rather slow and, therefore, the contact must be of long duration to bring about the movement. When such organs come in contact with any support or any hard object the growth of the contact side is checked, while the other side continues to grow. The result is that the organs slowly coil round that object. This is a mechanism for climbing. Some climbers move clockwise, e.g. white yam (*Dioscorea alata* ; B. & H. CHUPRI-ALOO), while others anticlockwise, e.g. wild yam (*D. bulbifera* ; B. GACHH-ALOO ; H. ZAMINKHAND). If the direction be artificially altered, growth becomes arrested. Haptotropism is also exhibited by the tendrillar leaf-apex of glory lily (*Gloriosa* ; see fig. 63) and the petiole of pitcher plant (*Nepenthes* ; see fig. 64), garden

nasturtium (see fig. 126C) and virgin's bower (*Clematis*; see fig. 62).

2. **Light.** The movement of plant organs as determined by the direction of incidence of rays is called **heliotropism** or **phototropism.** Some organs grow towards it and are said to be *positively heliotropic,* as the shoot; and others grow away from it and are said to be *negatively heliotropic,* as the root. Dorsiventral organs such as leaves, runners, etc., grow at right angles to the direction of incidence of rays so that their upper surface is exposed to light; such organs are said to be *dia-heliotropic.* Positive heliotropism is markedly seen in plants, particularly the seedlings, when these are grown in a closed room or box (heliotropic chamber; fig. 500) with one open window on one side. They all tend to grow towards the window, i.e. towards the source of light, and in the case of the box they ultimately come out through it. The cause of phototropic curvature is now explained on the basis of *hormones* (see p. 349). The effect of this unilateral light may be eliminated by placing a pot plant on a **clinostat** (fig. 502) in the vertical direction and rotating the same. The plant is seen to grow vertically upwards and not to bend towards the window. The flower-stalk of ground nut (*Arachis hypogaea*; fig. 501) grows towards light, but after pollination it becomes negatively heliotropic and positively geotropic like the root. The stalk bends down and quickly elongates pushing the fertilized ovary into the ground where gradually the ovary ripens into pod (fruit). It is also seen, as in *Eucalyptus,* that the edge of the leaf is turned towards intense light, and when the light is diffuse the surface is exposed to it.



FIG. 500. Heliotropic chamber.

3. **Force of Gravity.** The movement of plant organs in response to the force of gravity is called **geotropism.** Geotropism has a marked effect on the direction of growth of plant organs. The primary root is seen to grow towards the centre of gravity, and the primary shoot away from it. The former is, therefore, said to be *positively geotropic,* and the latter *negatively geotropic.* The lateral roots and the branches usually grow at right angles to the force of gravity and are said to be *diageotropic.* That the direction of growth is deter-

mined by the stimulating action of the force of gravity is clearly seen in a seedling which has been placed in a horizontal

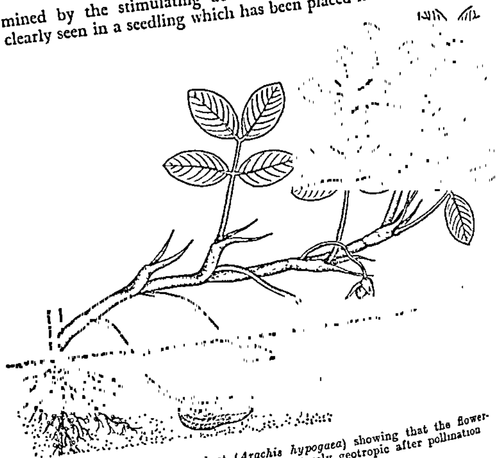


FIG. 501. Ground nut plant (*Arachis hypogaea*) showing that the flower-stalk is negatively heliotropic and positively geotropic after pollination of the flower.

position away from light. Both the stem and the root undergo curvature in their growing region behind the apex, passing through an angle of 90° ; the root curves and grows vertically downwards, and so does the stem upwards. It is the very tip of the root, for a distance of 1 to 2 mm. in length, that is sensitive to this stimulus ; but the actual bending takes place some distance behind the tip in the region of greatest growth. If the tip of the root be decapitated, no bending takes place. Besides, it is seen that the root of a germinating seed can, under the force of gravity, grow downwards even through mercury overcoming considerable pressure. Further, it has been found possible with the help of a **clinostat** (fig. 502) to eliminate the effect of geotropic stimulus on the root and the shoot by introducing a centrifugal force. This is done by rotating the seedling in a horizontal plane and thus subjecting all sides of the growing and sensitive regions to this force.

Under this condition the force of gravity cannot act on any definite part and, therefore, no geotropic movement becomes

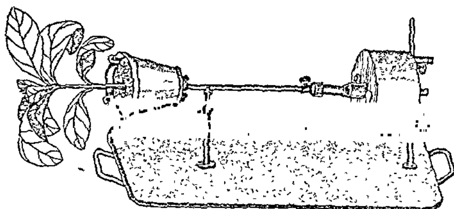


FIG. 502. Clinostat in the horizontal position to eliminate the effect of force of gravity.

possible. The cause of geotropic curvature is now explained on the basis of *hormones* (*see p. 349*).

Experiment 21. Geotropism. A clinostat (fig. 502) may be used to demonstrate geotropism. *A clinostat is an instrument by which the effect of* lateral light and the force of gravity on an organ of a plant—root or stem—can be eliminated. It consists of a rod with a disc mounted on it, to which a small pot plant may be attached, and a *clockwork mechanism for rotating* the rod and the disc. The clinostat works slowly—its rotation being ordinarily ¼ to 4 turns per hour. A plant, preferably a pot plant, may be fixed in the clinostat in any position—vertical, horizontal or at an angle—and made to rotate by clockwork mechanism in the clinostat. When the plant is horizontal, the root and the stem grow horizontally, instead of the root curving downwards and the stem upwards. This is due to the fact that all sides of the growing axes are in turn directed downwards, upwards and sideways so that the force of gravity cannot act on any definite position. This results in the effect of the force being eliminated altogether. The root and the stem cannot, therefore, bend. If, however, the plant be fixed in the vertical position and the clinostat rotated, it is seen that the plant grows in the vertical direction—the root downwards and the stem upwards.

4. **Temperature.** The movement or curving of an organ of a plant in response to the stimulus of heat or cold is called **thermotropism.** If a closed box containing seedlings be warmed on one side, it is seen that they curve towards the warm side.

5. **Chemical Substances.** The movement induced by the presence of certain chemical substances is spoken of as **chemotropism.** The tentacles of sundew respond to various nitrogenous substances placed on its leaf. Thus a drop of soluble protein or a bit of raw meat induces movement only after a *portion of it has been absorbed. On absorption the protoplasm* gets stimulated and it sends a motor impulse to the surrounding tentacles which bend down on the *protein or meat from* all sides. The pollen-tube grows towards the ovule being

stimulated by the sugary substance secreted by the stigma, the style and the ovary. Sucking roots of parasites and hyphae of parasitic fungi penetrate into the tissue of the host plant in response to the stimulus of cerain chemical substances contained in the latter. Similarly, respiratory roots of many plants growing in estuaries curve upwards from the soil into the air, that is, towards the source of oxygen in response to the stimulus of the latter (see figs. 522-3).

6. **Moisture.** The movement of an organ in response to the stimulus of moisture is known as **hydrotropism.** Roots are sensitive to variations in the amount of moisture. They show a tendency of growing towards the source of moisture, and are said to be *positively hydrotropic.* It is seen that roots of plants growing in a hanging basket made of wire-netting and filled with moist sawdust project downwards at first, coming out of the basket, under the influence of the force of gravity, but they soon turn back in response to the stimulus of moisture (moist sawdust of the basket) and pass again into the basket having formed loops.

Experiment 22. Hydrotropism. A porous clay funnel, covered around with a filter paper, is placed on a wide-mouthed glass bottle (or hyacinth glass) filled with water, as shown in fig. 503. The paper is thus kept moist. The porous funnel is filled with dry sawdust and the soaked seeds arranged in a circle, each near a pore. It is necessary to add a few drops of water now and then to the seeds to help their germination. As they germinate it is seen that the roots, instead of going vertically downwards in response to the force of gravity, pass out through the pores towards the moist filter paper, and grow downwards alongside the paper into the bottle. Roots thus show movements towards moisture, or, in other words, they are positively hydrotropic.

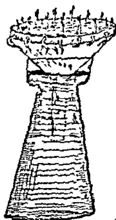


FIG. 503. Experiment on hydrotropism.

(b) Nastic Movements or Nasties. Like tropisms nastic movements of plant organs are induced by stimuli like contact, light and heat, but these movements are not directive, i.e. the direction of movement in such cases is not determined by the direction from which the stimulus is applied, or, in other words, from whichever direction the stimulus acts it equally affects all parts of the organs, and they always move in the same way and in the same direction. The direction in them is largely determined by the structure or anatomy of the organs concerned. Nastic movements are mostly exhibited by flat dorsiventral organs like leaves and petals. The following kinds of nasties are common:

1. **Seismonasty.** The movement brought about by

mechanical stimuli such as contact with a foreign body, poking with any hard object, drops of rain, a gust of wind, etc., is called **seismonasty.** Movements of the leaves (leaflets) of sensitive plant (*Mimosa pudica*; fig. 505), sensitive wood-sorrel (*Biophytum sensitivum*: B. BAN-NARANGA ; H. LAJALU—fig. 504), *Neptunia* (B. PANI-LAJUK), *Averrhoa* (B. KAMRANGA ; H. KAMRAKH), etc., are familiar examples. Leaflets of such plants close up, when touched. It is also to be noted that the degree of movement varies according to the intensity of the stimulus applied ; for example, when the leaf-apex of the sensitive plant is lightly touched, only a few pairs of leaflets close up ; when rather roughly touched or pinched, all the leaflets react in the same way from the apex downwards ; and when roughly handled, all the leaflets close up simultaneously and the leaf as a whole droops. Venus' fly-trap (*Dionaea* ; see fig. 484) is another very interesting example. The two lobes of the leaf of this plant are each provided with three hairs which are extremely sensitive to touch, and in contact with a foreign body, particularly a flying insect, the two lobes close up suddenly. In *Bignonia*, *Mimulus* and *Martynia* the two stigmatic lobes close up, when touched or when pollen grains fall on them. In the sunflower family (*Compositae*) and China

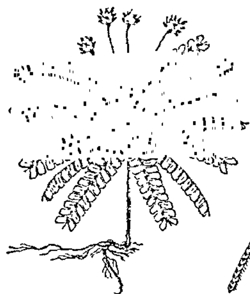


FIG. 504



FIG. 505

Fig. 504. Sensitive wood-sorrel (*Biophytum sensitivum*).
Fig. 505. Sensitive plant (*Mimosa pudica*).

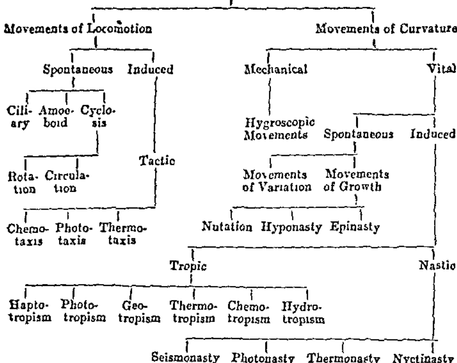
rose family (*Malvaceae*) it is seen that the stigmas bend down and touch the anthers to achieve self-pollination, in case cross-pollination fails. In barberry (*Berberis*), purslane (*Portulaca*; B. NUNIA-SAK; H. KULFA-SAG; P. LUÑAK), prickly pear (*Opuntia*; B. PHANI-MANSHA; H. NAGPHANI; P. CHITAR-THOR—see fig. 88), etc., the stamens are sensitive, and when touched by an insect they spring violently, strike the latter and dust it with pollen grains.

2. **Photonasty.** The movement induced by changes in the intensity of light is called **photonasty.** Many flowers open when there is strong illumination and close up on darkening or when artificially shaded. Some flowers open in weak light. With increasing intensity of light they close up. Flowers blooming at night are affected in the reverse way. Stomata open when light appears and close up when light fails.

3. **Thermonasty.** The movement induced by variations in the degree of temperature is called **thermonasty.** Many flowers open rather quickly at the rise of temperature and close up when the temperature falls. Similar effect is produced in the case of leaves of most *Leguminosae* and also of wood-sorrel (*Oxalis*). When the temperature rises high or falls low the leaves close up, and at optimum temperature they open.

4. **Nyctinasty.** The movement induced by alternation of day and night is called **nyctinasty** (or nyctitropism) or **sleep movement.** Leaves and flowers, particularly the former, are markedly affected by nyctinasty. Nyctinasty is affected by both the factors (light and temperature) acting simultaneously but always more so by light. This kind of movement is most remarkably exhibited by *Leguminosae*. Leaflets of these plants close up and often the leaf as a whole droops in the evening when the light fails, and they open up again when the light appears in the morning. A few other plants like *Chenopodium* (B. & H. BATHUA-SAK), *Averrhoa* (B. KAMRANGA; H. KAMRAKH), etc., also show the same phenomenon. Leaflets normally fold on their upper surface, and by doing so excessive radiation of heat is prevented during the night. Movement of this nature is due to difference in the turgidity of the cells of the pulvinus at the base of the leaf and the leaflets. Among the flowers showing nyctinasty mention may be made of *Gerbera* (a garden herb), *Portulaca* (wild or garden variety), etc.

The various kinds of movements that have already been described are scheduled on the next page:



C. PHYSIOLOGY OF REPRODUCTION

CHAPTER XIV

REPRODUCTION

Since the life of an individual plant is limited in duration it has developed various mechanisms to continue the perpetuation of the species and also to multiply in number. The following are the principal methods by which an individual reproduces itself. These methods are *vegetative, asexual* and *sexual*.

I. Vegetative Reproduction

A. Natural Methods of Propagation

In any of these methods a portion gets detached from the body of the mother plant, and this detached portion embarks on a new career under suitable conditions. Gradually it grows up into a new independent plant. The methods by which vegetative propagation takes place are many and varied.

1. **Budding.** In the case of yeast (see fig. 598) one or more tiny outgrowths appear on one or more sides of the vegetative cell immersed in sugar solution. Soon these outgrowths get detached from the mother cell and form new individuals. This method of outgrowth-formation is known as budding. Often budding continues one after the other so that finally a chain of cells is formed. *All the individual* cells of the chain separate from one another and form new yeast plants.

2. **Gemmae.** In some mosses and liverworts special bodies, known as gemmae (see figs. 624 and 627-8), develop on the leaf, branch or thallus for the purpose of vegetative propagation.

3. **Leaf-tip.** There are certain ferns, commonly called 'walking' ferns (e.g. *Adiantum caudatum, A. lunulatum* and *Polypodium flagelliferum*), which propagate vegetatively by means of a bud produced at the tip of the leaf (fig. 506). As the leaf bends down and touches the ground the tip strikes roots and forms a bud. This bud grows into a new independent fern plant. Ferns normally, however, reproduce vegetatively by their rhizome.



FIG. 506. Walking fern (*Adiantum caudatum*).

In the 'flowering' plants the methods of vegetative propagation are diverse. The offspring resulting from these methods resemble the parent forms in almost *all respects* and, therefore, the gardeners often take to these methods for multiplying the number of individuals for their gardens.

1. **Underground Stems.** Many 'flowering' plants reproduce themselves by *means of the rhizome*, the tuber, the bulb and the corm. New buds are produced on these modified stems, which gradually grow up into new plants. Common examples are afforded by ginger, potato, onion and saffron (see figs. 73-7).

2. **Sub-aerial Stems.** The runner, the stolon, the offset and the sucker are also made use of by plants like wood-sorrel (*Oxalis*; see fig. 78) and Indian pennywort (*Centella* = *Hydrocotyle*; fig. 507), taro (*Colocasia*; see fig. 79), water lettuce

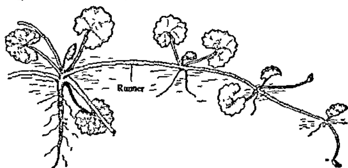


FIG. 507. Runner of Indian pennywort (*Centella*) showing vegetative mode of propagation.

(*Pistia*; see fig. 80) and *Chrysanthemum* (see fig. 81) for vegetative propagation.

3. **Adventitious Buds.** In sprout-leaf plant (*Bryophyllum pinnatum*; see fig. 34) a series of adventitious (foliar) buds are produced on the leaf-margin, each at the end of a vein,

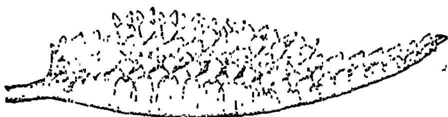


FIG. 508. A leaf of *Bryophyllum tubifolium* with adventitious buds.

these buds grow up into new plants. In *Bryophyllum tubifolium* (fig. 508) and *Kalanchoe* (fig. 509) there is profuse

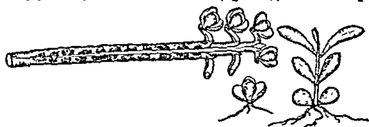


FIG. 509. A leaf of *Kalanchoe* sp. with adventitious buds.

bud-formation from the leaf on the plant itself. In elephant ear plant (*Begonia*; see fig. 35) a few adventitious buds are produced on the surface of the leaf from the veins and also

from the petiole. Similarly roots of some plants may produce adventitious (radical) buds for the same purpose, as in sweet potato, *Trichosanthes* (B. PATAL; H. PARWAL), wood-apple (*Aegle*) ipecacuanha (see fig. 45), etc

4. **Bulbils.** In *Globba bulbifera* (fig. 510) and garlic (*Allium sativum*) some of the lower flowers of the inflorescence become modified into small multicellular bodies, known as bulbils. These fall to the ground and grow up into new plants. Sometimes they are seen to grow to some extent on the plant itself. In American aloe or century plant (*Agave*; fig. 512) and in some species of *Crassula* vegetative reproduction takes place by the formation of reproductive buds, also called bulbils, in place of many flowers of the inflorescence. Bulbils, big or small, are also produced in the leaf-axil of wild yam (*Dioscorea bulbifera*: B. GACHH-ALOO; H. & P. ZAMINKHAND—fig. 511) and *Lilium*



FIG. 510. *Globba bulbifera.* *B*, bulbil.

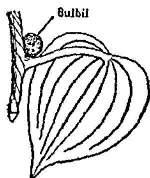


FIG. 511



FIG. 512

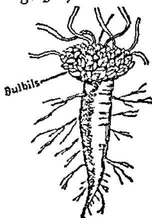


FIG. 513

Bulbils. Fig. 511. *Dioscorea bulbifera.* Fig. 512. Bulbil of American aloe (*Agave*). Fig. 513. Wood-sorrel (*Oxalis*).

bulbiferum. In wood-sorrel (*Oxalis*; fig. 513) a large number of small buds (bulbils) may be seen on the top of the swollen tuberous root. These buds being brittle at the base easily fall off and grow up into new plants. In pine-apple (*Ananas*) the inflorescence generally ends in a reproductive bud; but in some varieties of pine-apple (fig. 514) the inflorescence becomes surrounded at the base by a whorl of such buds and also crowned by a few of them.

B. *Artificial Methods of Propagation*

In any of these methods a portion can be separated out by a special method from the body of the mother plant and grown independently. There are several such methods.

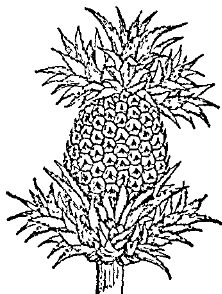


Fig. 514. Pine-apple with a crown and a whorl of bulbils.

1. **Cuttings.** (*a*) *Stem-cuttings.* Many plants like rose, sugarcane, tapioca, garden croton, China rose, drumstick (*Moringa*), *Duranta*, *Coleus* (see fig. 33), etc., may be easily grown from stem-cuttings. When cuttings from such plants are put into moist soil they strike roots at the base and develop adventitious buds which grow up. (*b*) *Root-cuttings.* Sometimes, as in lemon, citron, ipecacuanha (see fig. 45), tamarind, etc., root-cuttings put into moist soil sprout forming roots and shoots.

2. **Layering** (fig. 515). In this case a lower branch is bent down, a ring of bark to the length of 1-2 inches removed and this portion pushed into the soft ground keeping the upper part free. The bend is covered with soil and a stone or brick placed on it. When roots have developed, usually within 2-4 months, the branch is cut out from the mother plant and grown separately. Lemon, *Ixora*, rose, jasmines, grape-vine, etc., readily respond to this method.

3. **Gootee** (fig. [illegible]

[illegible]y, somewhat woody branch is selected and a ring of bark, 1-2 inches in length, sliced off from it. A sufficiently thick plaster of grafting clay, is applied all round the ringed portion which is then wrapped up with straw or rag and tied securely. It should be wetted with water every morning and afternoon. In drier climate an earthen pot with a hole at the bottom may be hung over the bandage in a convenient position, and the two connected

[1] Grafting Clay. Clay—2 parts, cowdung—1 part and some finely cut hay mixed with water.

by a long piece of cloth or soft cotton cord. As the pot is filled with water, the latter trickles down the cloth or cord and keeps the bandage constantly moist. Usually within 1-3 months the gootee is ready, as is indicated by its striking roots. It is then cut out below the bandage.

4. **Grafting.** This consists in inserting a small branch of a plant into a rooted plant of the same or allied species in such a way as to bring about an organic union (fusion of tissues) between the two and finally make them grow as one. The branch that is inserted is known as the *scion* or *graft*, and the plant that is rooted to the soil as the *stock*. The scion grows retaining all its qualities, while the stock which may be of inferior quality but physically sturdy supports it by supplying water and raw food material. Grafting thus ensures the production of particular desired characters in the plant, originally exhibited by the scion-mother. Grafts are prepared for the purpose of propagation of certain fruit- and ornamental shrubs and trees. Some of the common methods are as follows:

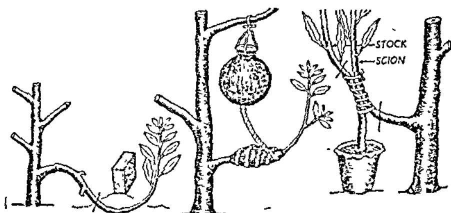


FIG. 515 FIG. 516 FIG. 517

Artificial Methods of Propagation. Fig. 515. Layering Fig. 516. Gootee. Fig. 517. Inarching or approach grafting.

(*a*) **Inarching or Approach Grafting** (fig. 517). By this method a branch (scion) of a plant is made to unite with a seedling (stock) by firmly tying them together with a cord. Before doing this a small portion of the bark is sliced off from each to ensure a closer contact and a quicker union between the two. When proper fusion has taken place, usually within 2-3 months, the stock is cut out above the joint and the scion below, thus leaving the scion standing on the stock. Some of the fruit trees like mango, litchi, guava, sapodilla plum, etc., readily respond to this method.

(*b*) **Bud Grafting** (fig. 518). For this method a T-shaped incision is made in the bark of the stock, and a bud cut out clean from a selected plant is inserted into the T-shaped slit and properly bandaged. By this method it has been found possible to grow several varieties of roses on one rose stock.

good varieties of orange, lime, lemon, citron, pummelo, etc., on inferior stocks, several varieties of *Hibiscus* on one, several varieties of cacti on one, and so on. Luther Burbank of California was able to grow by bud grafting several varieties of prune and allied species on one stock.

(c) **Whip or Tongue Grafting** (fig. 519) The stock, usually ½-¾ inch thick, is cut down a few inches above the ground. Sloping cuts are then made in it 2 or 3 inches long, as shown in the figure. The scion of the same thickness is also cut in such a way as to fit exactly into the stock. It is then inserted into the stock and tied firmly. The wound is of course covered with grafting wax[1]. All buds are removed from the stock but not from the scion.

(d) **Wedge Grafting** (fig. 520) The stock is cut 8-10 inches above the ground and the wood of the stem incised with clean cuts in the form of a V. The scion cut obliquely downward so as to closely fit into the stock is inserted into the stock and tied firmly. Grafting wax is used covering the wound.

(e) **Crown Grafting** (fig. 521). An old tree may be rejuvenated by this method. The stem is cut across 8 or 10 inches above the ground. The

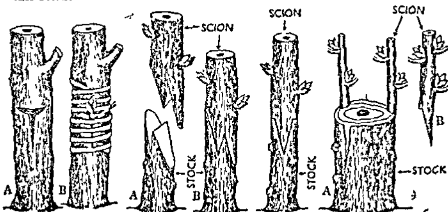


Fig. 518 Fig. 519 Fig. 520 Fig. 521

Artificial Methods of Propagation (*contd*) Fig. 518. Bud grafting. Fig. 519. Whip or tongue grafting. Fig. 520. Wedge grafting. Fig. 521. Crown grafting.

bark of the stock is cut through from the surface downward to a length of 5-6 inches. The bark is partially opened on either side. Prior to this a small branch cut out from another tree of the same species is incised at the base with a sloping cut and this is now inserted into the slit in the bark and tied firmly. The wound is of course covered with grafting wax.

II. Asexual Reproduction

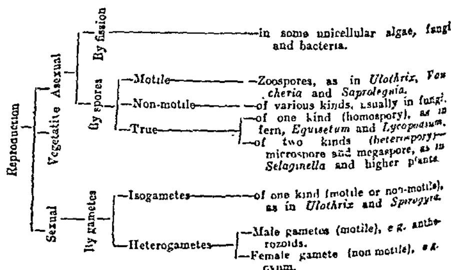
This takes place by means of special cells or asexual reproductive units produced by the parent plant to grow by themselves into new individuals, without two such cells fusing together, as in sexual reproduction. Asexual reproduction takes place by two methods: by fission and by spore formation.

A. **By Fission.** In the simplest cases, as in many unicellular algae and fungi and in bacteria, the mother cell splits

[1] Grafting Wax. A mixture of tallow—1 part, beeswax—1 part and resin—4 parts melted together and worked into a soft dough under water.

known as **heterogametes** (*heteros*, different), and the plants bearing such gametes are said to be **heterogamous.** In higher algae, fungi, mosses, ferns and allied plants male gametes are very minute, *motile, ciliated* and *active*, and are known as **antherozoids** or **spermatozoids.** The female gamete in them is *stationary, non-ciliated* and *passive*, larger in size, and is known as the **egg-cell, ovum** or **oospere.** The corresponding male and female reproductive units in the 'flowering' plants are the **two gametes** of the pollen tube and the **ovum** or **egg-cell** of the embryo-sac within the ovule. After fertilization the egg-cell clothes itself with a cell-wall and becomes teh **oospore.** The oospore gives rise to the **embryo,** and the ovule as a whole to the **seed.** The seed on germination gives rise to a new plant. The ovule and the seed are characteristic of phanerogams, and are altogether absent from cryptogams.

Gametes are always borne by the gametophyte. Moss is a gametophyte; it directly bears the gametes. In pteridophyta the gametes are borne by a small green body, called the prothallus; so the prothallus is the gametophyte. The product of union of two gametes is known as the **zygote.** The zygote is known as the **zygospore** when it is the product of fusion (conjugation) of two similar gametes, and it is called the **oospore** when it is the product of fusion (fertilization) of two dissimilar gametes—male and female. In the 'flowering' plants the gametophyte is an extremely reduced body.



IV. Special Modes of Reproduction

1. **Apospory** (*apo*, off or without). Apospory is the development of the gametophyte from a cell of the *sporophyte*

without the intervention of a spore. In some ferns it is sometimes seen that the prothallus develops on the undersurface of the leaf in the place of spores. The prothallus so formed bears antheridia and archegonia. It is also found in some mosses. In the 'flowering' plants it is sometimes seen that an embryo may be formed from the diploid cells of the nucellus, as in orange, mango, prickly pear (*Opuntia*), etc., or even from those of the integument, as in onion (*Allium*). The embryo thus formed is pushed into the embryo-sac during the course of its development. Since the nucellus or the integument belongs to the sporophyte the production of the embryo from the tissue of the sporophyte without the intervention of the spore is a case of apospory.

2. **Apogamy** (*apo*, off or without). Apogamy is the development of an embryo from a cell of the gametophyte other than an egg-cell, evidently without the intervention of gametes. The embryo so formed grows into the sporophyte. It is of common occurrence in ferns. In the 'flowering' plants it is sometimes seen that one or more embryos may be formed from the synergids, as in onion (*Allium*), lily (*Lilium*), aconite (*Aconitum*) and *Iris*, or from an antipodal cell, as in onion (*Allium*), or from the endosperm, as in *Balanophora* (a total root-parasite—see fig. 68).

3. **Parthenogenesis.** The development of the zygote from the egg-cell without the act of fertilization, as seen in many lower plants, e.g. *Spirogyra, Chara, Mucor, Saprolegnia*, and in many ferns, is known as **parthenogenesis.** In some species of 'flowering' plants the embryo also may develop by parthenogenesis, i.e. without fertilization. In them the embryo may develop from haploid egg-cell or diploid egg-cell. In the former case although germination is more or less normal, the plant becomes small and sterile. In the latter case the plant is normal in all respects. Sometimes the ovary normally develops into a *fruit without pollination and fertilization.* This type of fruit development is called **parthenocarpy.** Parthenocarpic fruits are almost always seedless. Examples are found in certain varieties of banana, pine-apple, guava, grapes, apple, pear, papaw, *Thalictrum, Alchemilla* and some species of *Compositae and Solanaceae.* It is rather peculiar that sometimes fruit formation may be induced by artificial pollination by foreign pollen from another species or even genus, but without subsequent fertilization. Sometimes mere spraying with certain chemicals (growth-promoting substances) like naphthalene-acetic acid results in the setting of fruits without fertilization (induced parthenocarpy).

Polyembryony. The occurrence of more than one embryo in the seed is known as *polyembryony*. *Many species of both* dicotyledons and monocotyledons exhibit this phenomenon. Polyembryony is, however, particularly common among conifers (see fig. 722). These embryos may be formed in the seed in a variety of ways: (1) there may be more than one egg-cell in the embryo-sac or more than one embryo-sac in the ovule, and all the egg-cells may be fertilized; or (2) a number of embryos may develop simultaneously *from different* parts ot the ovule. Thus they may be formed from the synergids and antipodal cells (vegetative apogamy), from the fertilized, egg-cell or unfertilized egg-cell (parthenogenesis), and from the tissue of the nucellus and the integument by sporophytic budding (apospory). Examples have been found in onion, ground nut, mango, lime, lemon and orange (but not in shaddock and citron). Polyembryony is commonly found in conifers where there are many archegonia in the ovule. All the archegonia may be fertilized resulting in the formation of as many embryos as there are archegonia; but ultimately one embryo reaches maturity, while others die off. In addition, one or four embryos may be formed in *Pinus* from the fertilized egg-cell.

PART IV

ECOLOGY

CHAPTER I

PRELIMINARY CONSIDERATIONS

Ecology (*oikos*, house ; *logos*, discourse) deals with the relations between plants or a plant community, or animals or an animal community (as they exist in their habitats) and the various factors of their environment. It investigates the various structural and functional peculiarities that have appeared in response to the conditions prevailing in the locality (environment). Ecology, therefore, involves both morphology (external and internal) and physiology. It should also be noted that plants give food and shelter to animals; while the effects of animals and human communities on plants are also manifold. A study of ecology necessarily includes both animals and plants, and also the interactions between them.

Environment. Environment includes all the factors that affect the form and growth not only of individual plants, but also of plant associations. Environmental factors may be **climatic** or **edaphic.** The climatic factor includes temperature, light, water (rainfall), humidity and wind, and the edaphic factor includes physical and chemical properties of the soil (including its water-contents). To these two, may be added the **biological** factor which includes bacteria and protozoa mainly in the soil, and also other living plants and animals including human beings.

A. **Climatic Factors.** These include all the conditions of the atmosphere such as temperature, light, water (rainfall), wind, etc., affecting primarily the shoot system of the plant.

1. **Temperature.** A certain temperature is essential for all the vital functions of the plant and for its growth. Temperature has practically no effect on the plant so far as change of form or structure is concerned. Under certain conditions some organs of the plant are thermotropic; for instance, the opening and closing of flowers and of stomata, the drooping of leaves at night, etc., are caused by heat. In many cases temperature helps the dehiscence of fruits and thereby causes dissemination of seeds. Plants normally prefer a temperature

varying from 20°C. to 40°C. The power of active tissues filled with water to withstand extremes of temperature is much less than dry seeds and spores. Most flowering plants are killed at a temperature below 0°C. and above 45°C., while seeds remain uninjured at a temperature far beyond these limits. Freezing temperature or frost kills plants, but at high altitudes where frosts frequently occur plants become unusually resistant. Temperature has an important bearing on plant geography. We find a considerable difference between the flora of tropical, sub-tropical, temperate, arctic and alpine regions.

2. **Light.** Physiologically light is a very important factor. It is responsible for the formation of chlorophyll and for carbon-assimilation; it accelerates transpiration. Although strong light checks growth it has a tonic effect on plants. Light induces certain kinds of movements like photonasty and phototropism. Relative length of day and night has a marked effect on the development of flowers and maturation of fruits. Of all parts of the plant the leaves undergo by far the greatest modifications under the action of light. Plants growing in shady places, called **sciophytes**, usually have large leaves which are thin in texture and are sparsely distributed on the stem; the stem is thin with long internodes; both the stem and the leaves are glabrous; palisade tissue is poorly developed; the leaf consists largely or entirely of spongy tissue; epidermis often contains chlorophyll and the cuticle is thin; stomata may be present on both sides. Common examples are *Begonia*, aroids, wood-sorrel, ferns, mosses and liverworts. Plants which can only grow well in the light, called **heliophytes**, on the other hand, have small leaves which are thicker and crowded together on the stem; the stem is stouter with short internodes; the stem and sometimes the leaves are very hairy; palisade tissue is well developed; epidermis is provided with a thick cuticle, but no chlorophyll; stomata are present on the lower side, often sunken or occluded. Aqueous tissue is often present. Most thick-leaved plants are heliophytes. Heliophytes include all xerophytes, prairie, meadow mesophytes and floating hydrophytes; while sciophytes include mesophytes of thickets and forests and submerged hydrophytes, as in deep ponds, lakes and the sea.

3. **Water.** It is the most important factor. It is responsible for various structural modifications of plants. Water is indispensable for all the vital functions of the plant. Protoplasm is saturated with water, and often we find that over

90% of the total weight of active tissues is water. The source of water for terrestrial plants is rain. Rainfall has a marked effect on the geographical distribution of plants. Availability of rainwater depends on the water-retaining capacity of the soil, as also often on plants themselves. The soil may be *physically dry* or sometimes *physiologically dry* due to the cold state of the ground or the preponderance of salts in it. Topographical factors are also very important in this respect. Cherrapunji in the Khasi hills, the rainiest spot in the world with an annual rainfall of over 450 inches, has a very luxuriant vegetation: while Rajputana with very little or no rain is extremely arid. It should also be remembered that abundance or scarcity of available water determines the life-cycle of the plant, the duration of plant growth and the time of reproduction in addition to certain well-marked features of the plant. Two extremes are hydrophytes and xerophytes (see pp. 378 and 380).

4. **Wind.** Wind has usually a destructive action on vegetation. It enhances transpiration; very strong, dry wind is often fatal to plants, particularly to young seedlings. In forests it has been seen that some plants can resist the action of wind far better than others. On the seashore coconut-palm is exposed to strong gusts of wind. The plant can withstand them well because its leaves are cut into narrow segments with stout mid-rib; the cuticle also is very thick. Wind is useful in disseminating seeds and fruits, particularly those provided with some kind of appendages (see pp. 162-6). In deserts there are certain species which, when the air is dry, roll up into balls and are driven by wind from one place to another (see p. 382). They strike roots and grow when the conditions are favourable.

B. **Edaphic Factors: Soils** (see Chapter II, Part III). Soils are formed by the disintegration and decomposition of rocks due to weathering and the action of soil bacteria, soil protozoa, earth-worm, etc. All soils are made up of particles —coarse or fine. Small particles (·2 to ·02 mm.) are said to form sand; very fine particles (less than ·002 mm.) form clay; and those of intermediate size (·02 to ·002) form silt. Soils supporting plant life are composed of sand, clay, silt, lime, organic matter, water and salts. Physically soils may be classified into (1) clay soil containing more than 30% of clay, (2) sandy soil containing 10% each of clay and silt, and (3) loam containing more or less 30% each of clay and silt. **Clay soil** is badly aerated and water-logged. It has a great capacity for retaining water, particles being very fine. Drainage in

this soil is difficult, while capillarity increases considerably. It is, however, heavy and easily becomes compact. **Sandy soil** on the other hand is always well aerated, being porous; but as it allows easy percolation through the coarse particles it often remains dry. Capillarity decreases in this soil. It is light. **Loam** is the best soil for vigorous plant growth because all the important physical conditions are satisfied—porosity for better aeration, percolation for downward movement of excess water, and capillarity for upward movement of sub-soil water. **Humus** (see p. 278) is also of considerable importance to plants both physically and chemically.

The chemical nature of the soil is also of considerable importance in the distribution of species. In nature, however, nutrient salts are very widely distributed. But the preponderance of salts (particularly sodium chloride) in the soil or water makes it physiologically dry, and the plants show xerophytic adaptations. All rich soils contain a certain amount of organic matters derived from the dead bodies of animals and plants. Shed leaves and roots left in the soil contribute materially to the amount of organic matters found in the soil. Various salts of nitrogen (N), sulphur (S), phosphorous (P), calcium (Ca), magnesium (Mg), potassium (K) and iron (Fe) present in the soil are indispensable for plant growth. Recent investigations show that boron (B), manganese (Mn), zinc (Zn), copper (Cu) and molybdenum (Mo), and also aluminium (Al) in many cases, are also necessary.

The acidity or alkalinity of the soil is not less important for growth and distribution of plants than the availability of plant food in the soil or its physical condition. Soils containing a certain amount of lime are alkaline, and soils containing humus, as in marshes, are acid. Certain species of plants thrive on saline soil; others require more or less alkaline or acid condition. There are, however, some species, *Acacia arabica* (B. BABLA; H. & P. BABUL or KIKAR), for example, which are indifferent to this quality of the soil. We know that newly dug out earth from old tank beds, which is comparatively speaking quite acid, is very suitable for banana plants. Slowly but surely the soil around these plants loses its acidity and the plants suffer.

C. **Biological Factor.** The relation of the species to other living organisms is apparent in many cases. There is the competition with its neighbours for food, water and sunlight. It may be attacked by parasitic plants, or may be fed upon by animals; in some cases plants are of mutual help to each other, e.g. *symbionts*, (see p. 46). Symbiosis between bacteria

and leguminous plants may be recalled to mind in this connexion (see figs. 463-4). Soil bacteria, protozoa, earth-worms, rats, etc., are useful agents in altering the soil. They also damage vegetation. This leads us to see how closely interwoven are the lives of plants and animals.

Modes of Perennation. In one year plants have to pass through two unfavourable seasons—cold winter and dry summer. The most favourable season for plant growth is the season with plenty of rainfall and moderate temperature. During winter drought and summer drought plants are more or less dormant. There are also protective adaptations to *withstand heat or cold associated with dryness of the air.* Thus we find that the perennial herbs perennate by the underground rhizome, tuber, bulb or corm, produced by them ; the aerial parts of such plants die down, and then, when the conditions are favourable, the underground stem produces a new shoot. In the case of annual herbs we find the summer plants drying up with the approach of winter, and the winter plants drying up with the approach of summer. In such plants, seed perennation is the only means of survival. In deciduous trees leaves fall off annually in winter or in summer, and thus excessive loss of water by transpiration is prevented. Moreover, cork is formed as a protective covering (see p. 271). and the young buds are protected by bud-scales (see pp. 36 and 65).

Succession. Life on earth is not stable. Old forms are *continuously giving place to new ones. From year to year we* find the old weeds and herbaceous plants disappearing from a locality and new ones taking their place. In new land bare of vegetation, as happens on alluvial deposits, dried up lakes, etc., we find certain species of plants appearing and occupying it ; these soon give place to others ; these again to others until *a stable vegetation, adapted to the environment, is formed.* This succession also applies to primitive vegetation. Owing to erosion of rocks, deposition of new materials and ultimate accumulation of humus, the vegetation of a place passes through a series of changes. The primitive 'land vegetation' was xerophytic in nature. In places with adequate rainfall and suitable temperature the xerophytic vegetation becomes displaced by plants showing mesophytic habit, and finally mesophytic forests reign supreme. Likewise ponds become filled with humus and sometimes with silt so that the pond vegetation becomes replaced by marsh and swamp vegetation, i.e. shrubs and trees that can stand water-logging follow :

lastly owing to further drying up the final stage of forest vegetation is reached. In regions with scanty or no rainfall the original xerophytic vegetation continues.

CHAPTER II

ECOLOGICAL GROUPS

Although plants sometimes occur as isolated individuals, more commonly we find that they become adapted to the same environment and are associated together in groups. The groups may include different plant species, belonging to different families, and differing in shape, size, form and relationship, but they live under the same conditions of the soil, moisture, heat and light. Some of the common groups are described below.

1. *Hydrophytes*

Hydrophytes are plants that grow in water or in very wet places. They may be submerged or partly submerged, floating or amphibious. Their structural adaptations are mainly due to the high water content and the deficient supply of oxygen. The various adaptations met with in hydrophytes are as follows:

Adaptations. The main features of aquatic plants are the reduction of protective tissue (epidermis here is meant for absorption, and not for protection), supporting tissue (lack of sclerenchyma), conducting tissue (minimum development of vascular tissue) and absorbing tissue (roots mainly act as anchors, and root-hairs are lacking), and the special development of air-chambers for aeration of internal tissues.

The root system in hydrophytes is feebly developed and root-hairs and root-cap are absent. In some floating plants such as bladderwort (*Utricularia*; see fig. 488), hornwort (*Ceratophyllum*), etc., no roots are developed at all, and in submerged plants such as *Vallisneria* (see fig. 297), *Hydrilla*, *Naias*, etc., water, dissolved mineral salts and gases are absorbed by their whole surface. In plants like water lettuce (*Pistia*; see fig. 80), water hyacinth (see fig. 102), duckweed (*Lemna*; see fig. 23), etc., no root-cap develops, but an analogous structure called root-pocket (see p. 23) is formed instead.

The stem is soft and more or less spongy, owing to the development of a large number of air-cavities in it and also in the leaf, filled with gases: these air-cavities on the one

hand give buoyance to the plant for floating and on the other they serve to store up air (oxygen and carbon dioxide). The carbon dioxide that is given off in respiration is stored in these cavities for photosynthesis, and again the oxygen that is given off in photosynthesis during the daytime is similarly stored in them for respiration. There is a minimum development of the mechanical and the vascular tissues. Xylem is reduced only to a few elements, while phloem is reduced to a few narrow sieve-tubes. There is no cuticle on the epidermis, but it contains some chloroplasts. The stem and the leaf-stalk are in some cases provided with prickles and spines for defence against the attack of aquatic animals.

Aquatic plants may be fixed to the substratum or they may be floating freely. Leaves likewise may be submerged or floating. Submerged leaves are thin, and these often become elongated owing to subdued light under water; they are generally ribbon-shaped, finely dissected or linear. Cuticle is absent and so are usually the stomata; the latter, if present, are functionless. Exchange of gases and absorption of water and mineral salts take place through the epidermis of the leaf. The mesophyll is thin and not differentiated into palisade tissue and spongy tissue, and the epidermis contains chloroplasts to utilize the weak light under water. Floating leaves are well developed, and have a thick cuticle and a large number of stomata on the upper surface; no stomata or only functionless ones are present on the lower surface. Exchange of gases takes place through the upper surface, and absorption of water through the lower. Many air-cavities develop in them for the purpose of aeration and necessary buoyancy. Amphibious plants are subjected to alternate flooding and drying. They usually grow at the edge of a pool of water with lower leaves submerged and upper ones above water. Many such plants often show **heterophylly** (*heteros*, different; *phylla*, leaves), i.e. they bear different kinds of leaves on the same individual (see figs. 176 and 179).

Some Common Aquatic Plants. A. **Submerged:** *Vallisneria* (see fig. 297), *Hydrilla*, *Naias*, *Ottelia*, *Potamogeton*, etc. B. **Floating:** *Wolffia*, *Salvinia*, *Hydrocharis*, bladderwort (*Utricularia*; see fig. 488), hornwort (*Ceratophyllum*), duckweed (*Lemna*; see fig. 23), water lettuce (*Pistia*; see fig. 80), water hyacinth (*Eichhornia*), water chestnut (*Trapa*), *Neptunia* (B. PANI-LAJUK), *Azolla*, *Ceratopteris*—a water fern, etc. Of these the first five are rootless. C. **Plants with floating leaves:** water lily (*Nymphaea*; see fig. 753), lotus (*Nelumbium*), *Euryale* (B. & H. MAKHNA), *Limnanthemum*, etc. D. **Amphibious plants**

showing heterophylly: water crowfoot (*Ranunculus aquatilis*), water plantain (*Alisma plantago*), arrowhead (*Sagittaria*; see fig. 179), *Limnophylla heterophylla*, *Cardenthera triflora* (see fig. 176), etc.

2. **Hygrophytes**

These are plants that *grow in constantly moist situations*. They occur in *moist shady places*, in forests, or in the moist soil near water-logged localities. The *root system* and the vascular system in hygrophytes are poorly developed. Plants are stunted in growth, their parts generally soft and spongy, and the stem usually an underground *rhizome*. There is a feeble development of *mechanical tissues*. Leaves on the whole are *well developed, fully expanded*, and with numerous stomata. They are *smooth*, *shining* and with a thin cuticle. The situation in which these plants grow being moist, transpiration is not active, but to get rid of the excess water, *leaves* are provided with hydathodes (see fig. 418) through which exudation of water takes place in liquid form. Common hygrophilous plants are aroids, ferns, begonias, some grasses, etc.

3. **Mesophytes**

These are plants that grow under average conditions of temperature and moisture; the soil in which they grow is neither saline nor is it water-logged, and the temperature of the air is *neither too high nor too low*. Mesophytes are, therefore, intermediate between hydrophytes and xerophytes.

Adaptations. The root-system is well developed with the tap-root and its branches in dicotyledons, and a cluster of fibrous roots in monocotyledons; root-hairs are luxuriantly produced for the absorption of water from the soil. The stem is solid (and not spongy, as in water plants), erect, and normally branched. Thorns on the stem are absent or few. All the *different kinds of tissues*, particularly the mechanical and conducting tissues, have reached their full development in the mesophytes. The aerial parts of plants such as the leaves and the branches are provided with cuticle. In dorsiventral leaves the lower *epidermis is provided with numerous stomata*; there are few *stomata or none at all on the upper surface*. In erect leaves, as in monocotyledons, stomata are more or less equally distributed on both surfaces.

4. **Xerophytes**

These are plants that grow in deserts or in very dry places; they can withstand a prolonged period of drought uninjured;

for this purpose they have certain peculiar adaptations. Xerophytes are really drought-resistant plants. It is not that they thrive under desert conditions. The property of drought-resistance is not attributed to the anatomical features of such plants but to the capacity of the protoplasm to endure a high degree of desiccation with practically no injury. Dominant factors in a desert or a very dry region are: scarcity of moisture in the soil and the extreme atmospheric conditions such as intense light, high temperature, strong wind and aridity of the air. These being so, the xerophytic plants have to guard against excessive evaporation of water; this they do by reducing evaporating surfaces. They have also to adopt special mechanisms for absorbing moisture from the soil and for retaining it. Xerophytic characters are also found in plants growing in cold regions such as temperate and sub-arctic zones and high altitude, rocky beds, sandy regions, dry places with scanty rainfall, and in salt marshes.

Adaptations. Plants produce a long tap root which goes deep into the sub-soil in search of moisture; many of the desert plants which live for a short period produce a superficial root-system to absorb moisture from the surface-soil after a passing shower of rain. To retain the water absorbed by the roots, the leaves and stems of some plants become very thick and fleshy, as in Indian aloe (*Aloe*) and American aloe or century plant (*Agave*); sometimes, ~~roots also~~ become fleshy, as in *Asparagus*. Aqueous tissue develops in them for storing up water; this is further facilitated by the abundance of mucilage contained in them. Multiple epidermis sometimes develops in the leaf for the same purpose, as in oleander (*Nerium*). Modification of the stem into phylloclade for storing water and food and at the same time performing functions of leaves is characteristic of many desert plants, e.g. cacti (see fig. 88).

Leaves and stems are provided with thick cuticle; epidermal cells often become strongly cutinized to prevent loss of water by transpiration. In many cases the stem becomes reduced in size and provided with thorns, as in *Euphorbia spinosa*. Leaves are also reduced in size minimizing their evaporating surfaces. Thus these may be divided into small segments, as in *Acacia*, or modified into spines, as in many cacti and spurges (*Euphorbia*), or sometimes reduced to small scales only, as in *Tamarix* and *Asparagus*. In some plants, as in *Gnaphalium* and *Aerua*, there is a dense coating of hairs. Stomata are fewer in number—usually 10-15 per sq. mm., and these remain sunken in grooves and occluded. There is a

strong development of sclerenchyma in most of the xerophytes. Modification of the leaf into phyllode, turning its edge in the vertical direction in strong sunlight to minimize transpiration, is characteristic of Australian *Acacia* (see fig. 151). Under conditions of extreme dryness leaves of most xerophytic grasses and also of many other plants roll up, considerably reducing their evaporating surfaces. In such cases stomata also become shut up.

Many of the xerophytic herbs lie prostrate on the ground, completing their life-history within a short time, e.g. *Solanum xanthocarpum, Tribulus terrestris, Trianthema monogynum* and *Suaeda fruticosa*; some are perennial in habit. Many xerophytes are elaborately armed with prickles and spines.

Two very peculiar cases showing special xerophytic adaptations may be mentioned here. These are certain species of *Selaginella* and *Anastatica*. When the dry season prevails in the desert, these plants curl up into a sort of ball, and are driven about by the wind. They are fixed only when they reach wet soil or the rains begin.

Some Common Xerophytic Plants. Many spurges (*Euphorbia*), e.g. *Euphorbia royleana, E. neriifolia*, etc., many cacti, e.g. prickly pear (*Opuntia*), *Cereus, Pereskia*, etc., dagger plant (*Yucca*; see fig. 180), Indian aloe (*Aloë*), American aloe or century plant (*Agave*), *Capparis aphylla, Tamarix* (B. & H. BAN-JHAU; P. PILCHI), prickly poppy (*Argemone*), jew's slipper (*Pedilanthus*; B. RANG-CHITA; H. NAG-DAMAN), globe thistle (*Echinops*), safflower (*Carthamus*; B. KUSUM; H. & P. KUSAM), amaranth (*Amaranthus*; B. KANTA-NATE; H. & P. CHULAI), wild plum (*Zizyphus nummularia*), purslane (*Portulaca*; B. NUNIA-SAK; H. KULFA-SAG; P. LUNAK), Indian spinach (*Basella*; B. PUIN; H. POI), saltwort (*Salsola*), sea-blite (*Suaeda*), *Asparagus*, gum tree (*Acacia*), camel thorn (*Alhagi*), *Solanum xanthocarpum* (B. KANTIKARI; H. KATELI; P. KATELA), *Tribulus terrestris* (B. GOKHRI-KANTA; H. GOKHRU; P. BHAKHRA), *Trianthema* (H. PATHUR-CHATTA; P. BISHKAPRA), *Gnaphalium, Aerua* (B. CHAYA; P. BUIKALLAN), *Kochia indica*, madar (*Calotropis procera*), *Crotalaria burhia*, etc. Common xerophytic grasses are *Stipa, Sporobolus, Saccharum spontaneum* (B. KASH; H. KANS, P. KAIH), *S. munja* (B. SAR; H. & P. MUNJA), *Aristida*, etc.

5. Halophytes

These are plants that grow in saline soil or water, where there is preponderance of salt in the soil: hence halophytes show some special characters.[1] The majority of halophytes

[1] It was believed that the saline water or soil was physiologically dry and the plants showed xerophytic adaptations. In the light of recent observations it may be said that the so-called xerophytic adaptations are the result of reaction of excess of salts on the plants.

have succulent leaves ; some have a succulent stem also. Leaves may be modified into or provided with spines. Typical -blite (*Suaeda maritima*), saltwort B. HARGOZA ; H. HARKUCHKANTA), & H. BATHUA-SAK ; P. BATHU), *Basella* (B. PUIN ; H. POI) and some species of *Asclepiadaceae*



Mangrove plants showing (a) pneumatophores for respiration, (b) stilt roots for support, and (c) viviparous germination for survival.

Halophytes growing in marshy places near the seashore, as in the Sundarbans, form a special vegetation known as the

mangrove. Mangrove plants produce a large number of **stilt roots** (fig. 522) from the main stem and the branches. In several cases, in addition to the stilt roots special roots, called **respiratory roots or pneumatophores** (figs. 522-3), are also produced in large numbers. They develop from underground roots, and projecting beyond the water level they look like so many conical spikes distributed all round the trunk of the tree. In some places they grow so thickly that passage through them is difficult. These are provided with numerous pores or respiratory spaces in the upper part, through which exchange of gases for respiration takes place. Mangrove species also show a peculiar mode of germination. The seed germinates inside the fruit whilst it is still on the parent tree and is nourished by the latter. Germination is almost immediate without any period of rest. The radicle elongates to a certain

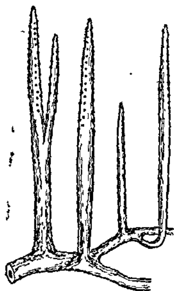


Fig. 523. Pneumatophores growing vertically upwards from an underground root.

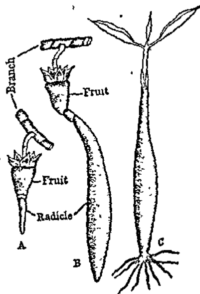


Fig. 524. Viviparous germination.

length and swells at the lower part. Finally the seedling separates from the parent tree and falls vertically down. The radicle presses into the soft mud, keeping the plumule and cotyledons clear above the saline water. Lateral roots are quickly formed for proper anchorage. The advantage is that the fruit cannot be swept away by tidal waves. This kind of germination of the seed inside the fruit whilst the latter still remains attached to the plant is known as vivipary (fig. 524). Typical mangrove plants are *Rhizophora*, *Ceriops* (B.

GORAN), *Sonneratia* (B. KEORA), *Heritiera* (B. SUNDRI), *Excoecaria* (B. GEO), etc.

6. Marsh Vegetation

A marsh is a tract of low, wet land. During the greater part of the year it remains covered with water ; for a shorter period it is dry. There is stagnant mud in a marsh with abundance of mineral salts. The water is alkaline or even neutral but not acid. *The peculiarity of marsh vegetation is* that the submerged parts show hydrophytic adaptations ; while the aerial parts have the peculiarities of land plants. From the margin to the mid-marsh the vegetation shows often three zones with, of course, certain amount of overlapping. The first or the outermost zone, lying nearest the dry land, is composed of plants whose roots or rhizomes are only in waterlogged areas. This zone exhibits to some extent the characteristics of hygrophytes. Leaves are usually well developed with numerous stomata but with thin cuticle, and the stem usually spongy in nature. There is dominance of low herbs in this zone, the common plants being water dropwort (*Oenanthe*), marsh pennywort (*Hydrocotyle*), various sedges (*Scirpus, Carex*, etc.), rush (*Juncus*), horsetail (*Equisetum*), etc.

The second or the intermediate zone lies between the first zone and the mid-marsh. Here the roots or rhizomes are in the wet soil under water, parts of the stem are in water, and the leaves and flowers are either floating or raised above water. This zone is characterized by tall herbs of upright growth. Typical plants of this zone are reed (*Phragmites*), *Arundo donax*, bulrush (*Typha*), etc. This zone is often called reed-swamp association. Low herbs or floating plants associated with them are water plantain (*Alisma*), water crowfoot (*Ranunculus*), water lilies (*Nymphaea*), lotus (*Nelumbium*), duckweed (*Lemna*), water lettuce (*Pistia*), arrowhead (*Sagittaria*), hornwort (*Ceratophyllum*), *Hydrilla, Vallisneria, Utricularia* as well as some floating grasses such as *Hygrorrhiza, Vossia* and *Panicum proliferum*.

The third or the innermost zone is submerged, and the vegetation typically hydrophytic. Common plants of this zone are *Potamogeton, Vallisneria, Hydrilla, Ceratophyllum*, etc. Besides, many of the aquatic plants of the second zone extend into this zone.

PART V
CRYPTOGAMS

CHAPTER I

DIVISIONS AND GENERAL DESCRIPTION

Cryptogams are plants which do not bear *evident* flowers and hence they are commonly known as 'flowerless' plants. They are better called 'seedless' plants since they never bear seeds. The method of reproduction in such plants remained unknown for a long time and hence the name 'cryptogams' (*kryptos*, concealed; *gamos*, marriage). They are broadly classified as follows:

I. **Thallophyta.** The plant body is a thallus, i.e. not differentiated into stem and leaf. These include (1) **algae**, i.e. thallophytes containing chlorophyll and sometimes also other pigments, (2) **fungi**, i.e. thallophytes without chlorophyll, (3) **bacteria**, i.e. unicellular, microscopic, non-green (without chlorophyll) organisms, and (4) **lichens**, i.e. compound organisms made of a fungus and an alga living in symbiotic partnership.

II. **Bryophyta.** The plant body is thalloid or *leafy*; regular alternation of generations; sporophyte always growing attached to the gametophyte as a dependent body. These include (1) **hepaticae or liverworts**, i.e. bryophyta with mostly thalloid plant body, and (2) **musci or mosses**, i.e. bryophyta with leafy stem.

III. **Pteridophyta.** The plant body is differentiated into the stem, leaves and roots; regular alternation of generations; sporophyte and gametophyte are independent of each other; main plant always a sporophyte; vascular tissues well developed and hence also called *vascular cryptogams*. These include ferns and their allies.

Thallophyta are primitive plants and are regarded as lower cryptogams, while bryophyta and pteridophyta are advanced plants and are regarded as higher cryptogams. From ferns upwards all plants have a well-developed conducting or vascular system; so such plants are otherwise known as *vascular plants*.

Reproduction. Of the three methods of reproduction, viz., vegetative, asexual and sexual, a particular plant may take to one or more methods. Vegetative reproduction commonly takes place by cell-division or by fragmentation. Asexual reproduction takes place by fission or by spores of varied types in different groups of plants. Sexual reproduction takes place by the fusion of two gametes, and the degree of sexuality passes through progressive stages—isogamy to anisogamy to oogamy. In the primitive forms of plants there is fusion of two gametes similar in shape, size and behaviour (isogametes); the fusion of such gametes is called **isogamy.** In other forms the two gametes may be slightly different in size and behaviour (anisogametes); the fusion of such gametes is called **anisogamy.** In the advanced forms the gametes become differentiated into male (microgametes) and female (megagametes); their fusion is called **oogamy.** In oogamous forms the male gamete is small motile ciliated active and initiative and is called **antherozoid** (spermatozoid or simply sperm), while the female gamete is large non-motile non-ciliated passive and receptive and is called **egg** (egg-cell, ovum or oosphere).

Alternation of Generations. The life-history of many plants (higher algae, liverworts, mosses, ferns and their allies) is complete in two stages or generations, alternating with each other. These two generations differ not only in their morphological characters but also in their modes of reproduction. One generation reproduces by the asexual method, i.e. by spores, and the other by the sexual method, i.e. by gametes. The former is, therefore, called the sporophytic or asexual generation, and the latter the gametophytic or sexual generation. To complete the life-history of [illegible] plant one generation [illegible] the sporophyte and [illegible] or in other words, the two generations regularly alternate with each other. This alternation of gametophyte with the sporophyte and *vice versa* is spoken of as alternation of generations.

Cytological Evidence of Alternation of Generations. In order to keep the chromosome number the same through successive generations plants reproducing sexually (fertilization), evidently with the doubling of chromosomes in the zygote as a result of fusion of two gametes, must have a counter-stage (meiosis) involving reduction of chromosomes. It is a fact that the gametophyte always possesses half as many chromosomes as the sporophyte, or in other words, if the sporophyte bears $2n$ or diploid chromosomes the gametophyte

would bear n or haploid chromosomes (n signifying the number of chromosomes). At the time of reproduction the sporophyte bears spore mother-cells (each with $2n$ chromosomes). These undergo meiosis or reduction division and the chromosome number is reduced to half in the spores, evidently with n or haploid chromosomes. The spore germinates and gives rise to the gametophyte. The spore, therefore, represents the beginning of the gametophytic generation. The gametophyte, evidently with n chromosomes, in due course bears gametes. When the two gametes (male and female, each with n chromosomes) fuse to form the zygote the chromosome number is doubled, i.e. it becomes $2n$. The zygote develops into the sporophyte with $2n$ chromosomes in all its cells. The zygote, therefore, represents the beginning of the sporophytic generation which continues right up to the spore mother-cells.

We may summarize, therefore, that spores, gametophyte, sexual organs and gametes, all with n chromosomes (i.e. the phase interpolated between fertilization and meiosis) represent the gametophytic generation, and zygote, sporophyte, sporangium and spore mother-cells, all with $2n$ chromosomes (i.e. the phase interpolated between meiosis and fertilization) represent the sporophytic generation, and that haploid (n) or gametophytic generation begins with the spore and ends in the gametes, while the diploid ($2n$) or sporophytic generation begins with the zygote and ends in the spore mother-cells.

In most green algae and most fungi the $2n$ or diploid phase is represented only by the zygote and not by any definite structure developing from it, which may be regarded as a sporophyte. In them, therefore, there is no true alternation of generations. But in the higher green algae, some fungi, most brown algae and red algae, and more particularly in the higher cryptogams—liverworts, mosses, ferns and their allies—an alternation of generations is, however, very regular. In them progressive stages in the development of the sporophyte and reduction of the gametophyte can be traced, culminating in the 'flowering' plants. In the latter the main plant body is always a sporophyte, and the gametophyte is represented only by a few cells (gymnosperms) or by a few nuclei (angiosperms).

CHAPTER II

ALGAE

Differences between Algae and Fungi. (1) Algae are green thallophytes containing the green colouring matter *chlorophyll*. In many algae the green colour may be masked by other colours, but in all of them chlorophyll is always present; *fungi, on the other hand, have no chlorophyll in them.* (2) Algae are *autotrophic* plants, i.e. they manufacture their own food with the help of chlorophyll contained in them; whereas fungi are *heterotrophic*, i.e. their modes of nutrition are diverse; they have to depend on prepared food materials supplied to them. They are either parasitic or saprophytic in habit. (3) The body of the algae is composed of a *true parenchymatous tissue*, but the body of the fungi is composed of a *false tissue*, or pseudo-parenchyma, which is an interwoven mass of fine delicate threads, known as *hyphae*. (4) The cell-wall of an alga is composed of true cellulose, and that of a fungus of fungus-cellulose or chitin mixed with cellulose, callose, pectose, etc., in different proportions. (5) Algae live in water or in wet substratum; whereas fungi live as a parasite on another plant or as a saprophyte on decaying animal or vegetable matter. (6) Reserve carbohydrate in algae is usually starch, but in fungi it is glycogen.

In structure both the groups may be unicellular, multicellular, filamentous or thalloid, and reproduction in them may take place vegetatively by cell-division or by detachment of a portion of the mother plant, or asexually by spores, or sexually by gametes.

Classification of Algae (20,000 sp.)

Class I. Cyanophyceae or Myxophyceae or blue-green algae, e.g., *Gloeocapsa, Oscillatoria* and *Nostoc.*

Class II. Euglenophyceae, e.g. *Euglena.*

Class III. Chlorophyceae or green algae, e.g. *Chlamydomonas, Eudorina, Volvox, Ulothrix, Spirogyra, Oedogonium* and *Vaucheria.*

Class IV. Phaeophyceae or brown algae, e.g. *Fucus.*

Class V. Rhodophyceae or red algae, e.g. *Polysiphonia.*

CLASS I. CYANOPHYCEAE OR MYXOPHYCEAE
or blue-green algae (1,400 sp.)

General Description. Cyanophyceae or Myxophyceae blue-green algae are a small group of primitive algae cl...

terized by the presence of a blue pigment *phycocyanin* in addition to chlorophyll (together making a blue-green colour), simple construction of the plant body, not clearly differentiated protoplast, and simple method of reproduction. Some species are truly unicellular, while in others the daughter cells after divisions adhere together to form a chain of cells (filament) or a flat or spherical colony. A great majority of them are fresh-water dwellers and often abundantly found in almost every stagnant pool of water, wet ground and as road slime after rains. The cell-structure is of primitive type. There is no definite nucleus nor any plastid, and the protoplast is differentiated into a peripheral coloured zone—the **chromoplasm**, and an inner colourless portion—the **central body** (see fig. 526C). The cell-wall is made of cellulose and pectic compounds. Carbohydrate occurs in the form of glycogen, starch being altogether absent. A gelatinous sheath is a common feature in most of them. Some filamentous forms, particularly *Oscillatoria*, show a slow spontaneous movement. Blue-green algae never reproduce sexually nor do they bear any kind of ciliated bodies. The common methods of vegetative reproduction are cell-division in unicellular forms, breaking up of the colony in colonial forms, and fragmentation of the filament into short pieces called **hormogonia** (see fig. 526B) in filamentous forms. In some filamentous forms except *Oscillatoria* a vegetative cell may act as a resting spore, called **akinete** (see p. 394). In such forms again one or more enlarged vegetative cells with transparent contents and thickened walls may be seen ; these are called **heterocysts** (see p. 394).

1. *GLOEOCAPSA*

Occurrence. *Gloeocapsa* (fig. 525) represents a simple primitive form of unicellular blue-green algae. It is commonly found on wet rocks, wet ground, in a pool of water, often in laboratory aquaria, forming small masses of jelly. A small such mass examined under a microscope reveals a large number of single cells or small colonies of cells, oval or spherical in shape, lying embedded in a mucilaginous matrix.

Structure. A single cell, more or less spherical in shape, represents a *Gloeocapsa* plant. The protoplast of the cell is generally differentiated into two regions: a blue-green peripheral region with chlorophyll and phycocyanin diffused through it—the *chromoplasm*, and a central region with a mass of chromatin granules constituting an incipient nucleus—the *central body*. The plant is always unicellular but often

2-4, sometimes several, daughter cells are held together in a colony by the mucilaginous sheath which occurs in concentric layers surrounding the individual cells as well as the whole

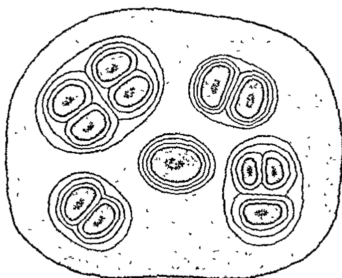


FIG. 525. *Gloeocapsa*—a cell and four colonies—embedded in gelatinous matrix.

colony. *Mucilage* is always derived from the *walls of the* individual cells.

Reproduction. *Gloeocapsa* reproduces vegetatively only by the process of cell-division. In this process the central chromatin matter divides first into two parts, and this is followed by the formation of a ring-like wall across the cell and its growth inward dividing the latter into two. Each daughter cell secretes its own mucilaginous sheath, grows and finally behaves as a new plant. Two or more such cells are frequently held together in a colony in a common mucilaginous matrix secreted by the individual cells. Sometimes a few species form thick-walled resting spores.

2. *OSCILLATORIA* (100 sp)

Oscillatoria (fig. 526A) is a dark blue-green alga. It consists of a slender, unbranched, cylindrical filament. It commonly occurs in ditches, in a shallow pool of water, wet rocks and walls, and in sewers. Filaments of *Oscillatoria* are entangled into masses which *float in water*. Each filament is made up of numerous short cells. The individual cells are the *Oscilla-*

oria plants, and the filament is regarded as a colony. All the cells are alike except the end cell which is usually convex, and there is no differentiation between the base and the apex. Here and there some dead and empty cells occur in some of the filaments. The protoplast of each cell is differentiated

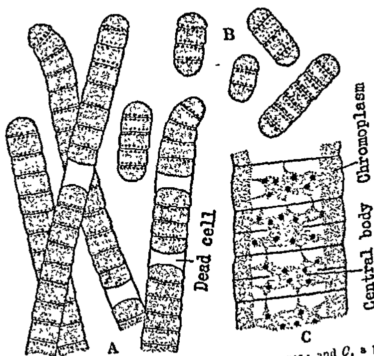


FIG. 526. *Oscillatoria*. *A*, filaments; *B*, hormogonia; and *C*, a portion of the filament magnified.

into two regions: a coloured peripheral zone—the **chromoplasm**, and an inner colourless zone—the **central body** (fig. 526C). The colour is due to the presence of chlorophyll and phycocyanin (a blue pigment) which diffuse through the chromoplasm and are not associated with any kind of plastids. Both the regions are granular in nature with various spherical or irregular inclusions which are mainly food grains, particularly glycogen and proteins. There is no true nucleus. The central body is, however, regarded as an incipient nucleus with only some chromatin but without nuclear membrane and nucleolus. Cell-division takes place in one direction only. Each filament remains enveloped in a thin mucilaginous sheath. Under the microscope a slow swaying or oscillating movement of the filaments with ends tossing from side to side may distinctly be seen. The filaments may sometimes exhibit a twisting or rotating motion. This is a characteristic feature of *Oscillatoria*.

Reproduction. In blue-green algae reproduction take place vegetatively by cell-division or by fragmentation of th filament, or asexually by spores. Gametes and zoospores ar altogether absent in them. In *Oscillatoria* the filament break up into a number of fragments, called **hormogonia** (fig. 526B) Each hormogonium consists of one or more cells and grow into a filament by cell-divisions in one direction. The hormo gonium has a capacity for locomotion.

3. *NOSTOC* (29 sp.)

Occurrence. *Nostoc* (fig. 527) is a common blue-green alga of filamentous form. Species of *Nostoc* may be terrestria or aquatic, and generally occur in ponds, ditches and other pools of water, and also in the damp soil as little, somewhat

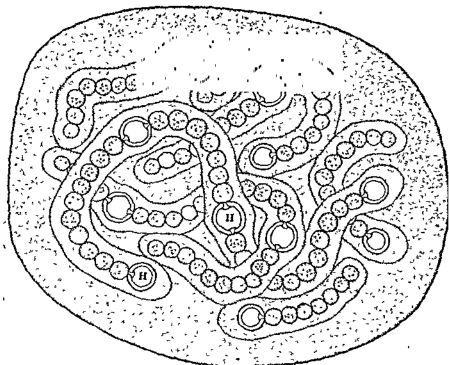


FIG. 527. *Nostoc* filaments embedded in gelatinous matrix. Note the heterocysts (H) with the polar nodules.

firm, masses of jelly. A few species are endophytic in habit occurring in the intercellular cavities of plants like *Anthoceros*, *Lemna*, root of *Cycas*, etc. Some lead a symbiotic life with a fungus forming a lichen.

Structure. Each gelatinous mass contains numerous slender filaments which under the microscope look like strings of beads. The filaments are interwoven forming an intricate mass. Each filament is unbranched and consists of a series of cells like beads in a chain, and is often invested by a gelatinous sheath of its own, in addition to the gelatinous matrix in which the tangled mass of filaments remains embedded. The sheath may be colourless or slightly tinged. The filament minus the sheath is commonly called a *trichome*. Each cell of the filament is more or less spherical or oval (sometimes barrel-shaped or somewhat cylindrical) in shape and blue-green in colour. The constitution of the cell is very much like that of *Gloeocapsa*. The filament increases in length by cell-division in one plane only. The divided cells grow and round off, and the filament elongates and appears like a beaded chain. A characteristic feature of *Nostoc* is the presence of some enlarged vegetative cells, at frequent intervals, with thickened walls and transparent contents; these are called **heterocysts.** At the two poles of each heterocyst there are two pores, one at each end, through which cytoplasmic connexion is maintained between the heterocyst and the adjacent vegetative cells. In the terminal heterocyst, however, only one such pore is formed. In any case each pore is later closed by a button-like thickening of the wall—the *polar nodule*. The function of the heterocyst is not definitely known (see below).

Reproduction. *Nostoc* reproduces vegetatively by fragmentation, and sometimes asexually by resting cells (spores), called akinetes.

Fragmentation. In vegetative reproduction the filament breaks up into a number of short segments, called **hormogonia.** Each hormogonium by repeated cell-divisions in one direction gives rise to a long filament. A large number of such daughter filaments may be seen in the gelatinous matrix. The fragmentation of the filament into hormogonia takes place at the junction of the heterocyst and the adjoining cell. (The function of the heterocyst is otherwise not definitely known. It may, however, sometimes act as a spore. It has also been suggested that the heterocyst is a food storage cell.

Akinetes. In a few species of *Nostoc* under unfavourable conditions, as in winter or during drought period, certain vegetative cells of the filament become enlarged and thick-walled containing reserve food; these are called resting cells (spores) or **akinetes** and may be produced singly or in a chain.

An akinete is regarded as a modified vegetative cell meant to act as a resting spore having no wall of its own distinct from that of the mother cell. According to the species the akinetes may develop anywhere in the filament or in a specific position in it, either close to or away from the heterocyst. Later under favourable conditions each germinates and gives rise to a *Nostoc* filament.

CLASS II. EUGLENOPHYCEAE

EUGLENA (over 18 sp.)

Euglena (fig. 528) is a most simple unicellular organism from which evolution of the higher forms of plants has possibly started. It belongs to the group Flagellatae in which the organisms are difficult to refer to the kingdom of plants or of animals. It grows in large numbers in polluted water containing organic substances, and colours it bright green. It is a single-celled, naked, free-swimming organism, elongated in shape, with one end blunt and the other end tapering. It is provided with a single cilium, i.e. a long, slender, whip-like projection, which vibrates and helps the plant to swim in water. It can also crawl by changing its shape (fig. 530). The protoplast contains a central nucleus, several green plastids, a contractile vacuole contracting and expanding in a few seconds, and a red spot near the blunt end, called the *eye spot*

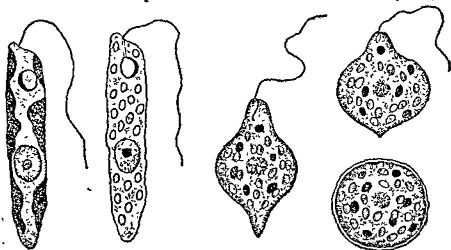


FIG. 528 FIG. 529 FIG. 530

Euglena. Fig. 528. Green form. Fig. 529. Colourless (saprophytic) form. Fig. 530. Various forms (three shown) assumed by a single cell.

(fig. 528). It feeds itself by photosynthesis and at the same time it ingests solid particles as food from the surrounding

water. When grown in the dark it loses its colour and leads a saprophytic life, obtaining nourishment from the aquatic medium in which it grows (fig. 529). It does not contain starch as the product of carbon-assimilation.

Reproduction. There is no sexual mode of reproduction in this plant. It multiplies by dividing longitudinally into two, the nucleus taking the initiative in the process (fig. 532). When the food supply falls short the protoplasmic contents contract and become surrounded by a thick wall which can then resist unfavourable conditions. This is known as the cyst or resting s p o r e (fig. 531A). The cyst germinates under favourable conditions when the wall becomes mucilaginous and the protoplast divides into 2, 4 or more bodies (fig. 531B). The divided bodies are set free as naked, unicellular organisms.

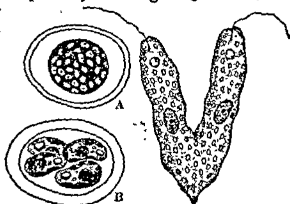


FIG. 531 FIG. 532

Eu ... *B*, cyst. ... *Euglena* cell.

CLASS III. CHLOROPHYCEAE

or green algae (5,500 sp.)

General Description. Chlorophyceae or green algae are characterized by the presence of green pigment or chlorophyll located in definite plastids (chloroplasts). They are mostly fresh-water algae, but some species are terrestrial and not a few are marine. Green algae exhibit a variety of forms—unicellular or colonial being motile or non-motile, multicellular being thalloid or filamentous; some species are coenocytic. The protoplast in all Chlorophyceae is well-organized with a definite nucleus (commonly one in each cell or numerous in a coenocyte) and one or more distinct chloroplasts. According to species or genera the chloroplasts vary in shapes and also in sizes—cup-shaped, plate-like, stellate, spiral, spherical, oval, discoidal, etc., containing one or more *pyrenoids* which are rounded protein bodies surrounded by a starchy envelope. The cell-wall is made of cellulose with often a layer of pectose external to it. Gelatinous sheath

may or may not be present. Most unicellular and colonial forms are provided with whip-like structures, called *cilia*—often 2, sometimes 4 or many—for motility of cells or colonies. In Chlorophyceae the cilia are of uniform length and always formed at the anterior end of the cell. In higher forms of Chlorophyceae cilia are restricted to the reproductive bodies only—zoospores and zoogametes. Primitive forms of Chlorophyceae have two or more contractile vacuoles and a small eyespot (see fig. 533).

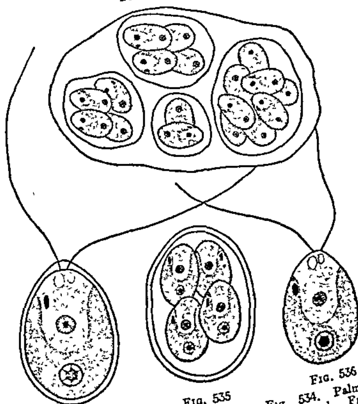
Reproduction. Vegetative reproduction takes place commonly by cell-division or by fragmentation. Asexual reproduction takes place by spores which are of varying types: a motile ciliated spore is called a **zoospore**; a non-motile non-ciliated spore with a distinct wall of its own but produced within a mother-cell is called an **aplanospore** (abortive zoospore); and a vegetative cell acting as a spore having no wall of its own—the wall of the mother-cell acting as the wall of the spore—is called an **akinete** (modified vegetative cell). Sexual reproduction takes place by **isogamy, anisogamy** or **oogamy** according to species. Whatever be the mode of sexual reproduction some species are **homothallic** (i.e. the pairing gametes come from the same parent) or **heterothallic** (i.e. the pairing gametes come from two separate parents). In many green algae it has been observed that a gamete grows *parthenogenetically* (i.e. without fusion with another gamete) into a new plant; the gamete thus behaves as a spore and is called **parthenospore.** Sometimes, as in *Spirogyra*, the gamete is without cilia and is called **aplanogamete.**

1. *CHLAMYDOMONAS* (43 sp.)

Occurrence. *Chlamydomonas* is a unicellular green alga found in ponds, ditches and other pools of stagnant water. A few species are found in snow in different regions forming blood-red patches due to the development of a red pigment by such species.

Structure. *Chlamydomonas* cells (fig. 533) are unicellular, usually spherical or oval in shape, with a thin wall. *Chlamydomonas* may be regarded as an intermediate form between the flagellate algae and the higher algae. The protoplasm at the anterior end of the cell is clear; it gives off two cilia and contains two contractile vacuoles which are pulsating in nature, undergoing alternate expansion and contraction.

These may be respiratory or excretory in function. There is a lateral orange or red pigment spot, commonly called the *eye spot*. This is sensitive to intensity of light. In the posterior region there is a single large cup-shaped chloroplast



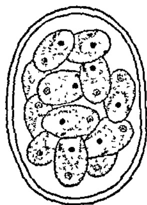
Chlamydomonas. Fig. 533. A mature cell. Fig. 534. Palmella stage. Fig. 535. Four daughter cells formed by asexual method Fig. 536. A daughter cell after escape.

with a pyrenoid in it. The pyrenoid consists of a central protein body surrounded by numerous minute starch grains. There is a nucleus more or less centrally placed. By the lashing of the cilia the cells quickly move about in water.

Asexual Reproduction. *Chlamydomonas* reproduces asexually by zoospores. In the formation of the zoospores the cilia of each cell are withdrawn, and the contents divide into 2, 4 or 8 cells, seldom more (fig. 535). The cells grow, develop two cilia each, and become motile zoospores. The wall of the mother cell dissolves and the zoospores are set free (fig. 536).

Palmella Stage. Under certain conditions the daughter cells instead of forming zoospores divide repeatedly into

numerous cells. Their walls become gelatinous, and the cells are held together by the gelatinous envelope of the mother



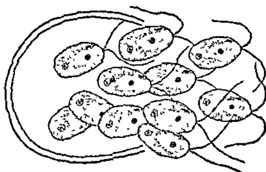
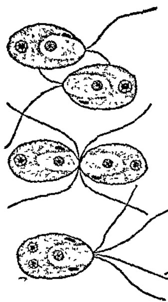


Fig. 537 Fig. 538
Chlamydomonas. Fig. 537. Gametes formed. Fig. 538. Gametes escaping.

cell. Thus numerous cells are seen to lie embedded in a gelatinous matrix. This is known as the palmella stage





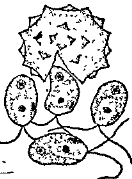


Fig. 539 Fig. 540
Chlamydomonas. Fig. 539. Free swimming gametes and conjugation. Fig. 540. *Top*, a resting zygote; *bottom*, four cells formed from the zygote

(fig. 537). When the conditions are favourable the cells develop cilia, swim out of the gelatinous matrix, and become motile again.

Sexual Reproduction. Sexual reproduction takes place by

motile ciliated gametes which are formed in the same way as the zoospores and are also alike excepting that they are somewhat smaller in size and more numerous—16, 32 or 64, or even more (figs. 537-8). All gametes are similar and are called *isogametes*, and their fusion is known as *isogamy*. Gametes of different parents usually conjugate in pairs (fig. 539). A zygospore—the product of fusion of two similar gametes—is formed. Their ciliate ends conjugate first. Soon after fusion the cilia are withdrawn and the zygospore clothes itself with a thick wall (fig. 540). It undergoes a period of rest, and then the contents of it divide and form 2 or 4 motile daughter cells (fig. 540). They grow in size, escape from the mother cell, and become individual motile *Chlamydomonas* cells.

It may be noted that in *Chlamydomonas* gametes are mostly alike (isogametes), while there are cases showing slight differentiation of gametes (anisogametes). Further, similarity of gametes and zoospores is suggestive of the origin of sexual cells (gametes) from asexual cells (zoospores) by transformation of the latter into the former.

2. *EUDORINA* (4 or 5 sp.)

Pandorina, *Eudorina*, *Volvox* and a few others are colonial algae in which the cells lie in a hollow mucilaginous sphere. Each colony, known as coenobium, consists of 16 cells in the case of *Pandorina*, 32 cells in the case of *Eudorina* and a few hundreds, often many thousands, in the case of *Volvox*, lying embedded in a spherical mucilaginous matrix.

Eudorina (fig. 541) is widespread in fresh water floating about in it. *Eudorina* cells are more or less spherical and lie

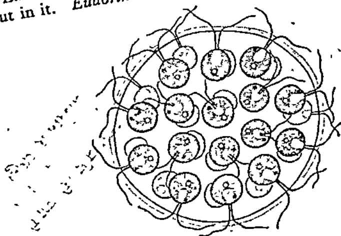


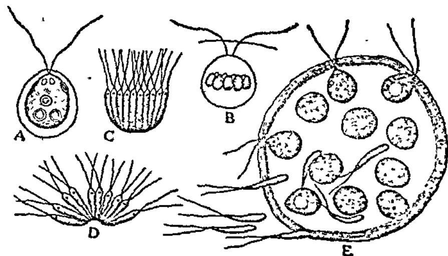
FIG. 541: *Eudorina* colony.

loosely towards the periphery of the mucilaginous sphere. T

cells are arranged in five tiers—the three middle tiers with 8 cells each, and the anterior and posterior tiers with 4 cells each. The cells remain connected by fine protoplasmic strands, hardly visible except by proper staining. Each cell (542A) has a mucilaginous sheath and is provided with two cilia. There is a distinct reddish-brown eye spot which is sensitive to light. Besides, there are two contractile vacuoles at the base of the cilia, a nucleus somewhere in the middle, and a cup-shaped chloroplast with 1 or more pyrenoids.

Asexual Reproduction. Each cell of the colony divides and forms its own small group of 32 cells. All the newly formed small colonies separate from one another by the disintegration of the mother colony. Each colony grows and forms a new mature coenobium.

Sexual Reproduction. Sexual reproduction takes place by differentiated gametes. The coenobia are dioecious being differentiated into male and female. The vegetative cells of the female colony enlarge to some extent, lose their cilia and come to lie near the surface of the mucilaginous sphere (542E). Each such cell is a single female gamete. The cells, often not all, of the male colony divide successively giving rise to a



Eudorina. FIG. 542. *A*, a single cell of the colony (note the two contractile vacuoles, eye spot, nucleus and two pyrenoids); *B*, *C* and *D*, stages in the formation of the male gametes; and *E*, a female colony with female gametes and some free swimming male gametes.

packet of 64 male cells (542B). The packet of cells moves out of the colony and swims as a unit to the female colony (542C-D). The packet then splits up into individual male

gametes or spermatozoids, as shown in (542E). The spermatozoids are more or less spindle-shaped and provided with two cilia. They swim into the female colony (542E) and each fuses with a female gamete to form an oospore. It is to be noted that two dissimilar gametes fuse in pairs ; so this is a case of *oogamy*. Several such oospores are formed. They remain in the female colony until the decay of the latter has set in. In the germination of the oospore its contents form one zoospore together with 2 or 3 smaller hyaline bodies (possibly degenerated zoospores). The zoospore divides repeatedly and soon forms a colony.

3. *VOLVOX* (over 12 sp.)

Volvox is a fresh-water, colony-forming, free-swimming, green alga occurring in ponds and other pools of water during and after rains. It often appears in abundance colouring the water green, particularly in the spring, and then abruptly disappears in the summer. During the rest of the year it lies dormant in the zygote stage.

Among the Volvocales this plant has reached the highest degree of colony formation. As a matter of fact each colony

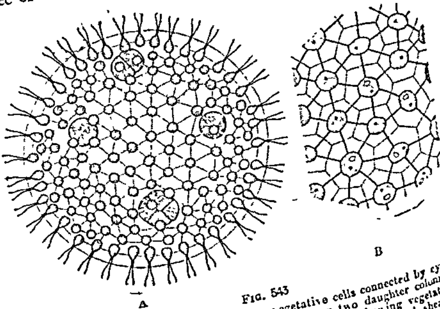


FIG. 543

Volvox. FIG. 543. A, a colony showing vegetative cells connected by cyt plasmic strands, four colony-forming cells (including two daughter colum and outer sheath : B, a portion of a colony (magnified) showing vegetati cells connected by cytoplasmic strands (thick lines) and polygonal shea (dotted lines).

or coenobium (*koinos*, common; *bios*, life), as it is called, consists of a few hundreds to several thousands (500 - 40,000) of cells which are so arranged in a peripheral layer as to form a hollow sphere (fig. 543A) containing water or a dilute solution of a gelatinous material. Each cell (fig. 543B) of the colony has a gelatinous sheath of its own, and at the same time the cells are held together in a colony by the sheaths secreted by the individual cells. The cells are connected by delicate but distinct strands of cytoplasm. The individual colonies, approximately 1 mm. in diameter, sometimes up to 2 mm., freely swim about in water. Each *Volvox* cell is very much like that of *Chlamydomonas*.

A mature colony (fig. 543A) shows two kinds of cells: *numerous small vegetative cells and a few (5-20) large cells* among the former. A vegetative cell has two cilia protruding outwards and vibrating, 2-5 contractile vacuoles, a central nucleus, a cup-shaped or plate-like chloroplast with one pyrenoid, and an eye-spot. The vegetative cells do not divide. The larger cells of the colony are the reproductive cells. These cells may behave exclusively as asexual cells or as sexual cells. Normally they act as asexual cells in the beginning of the season, and as sexual cells at the close of the season.

Asexual Reproduction *(fig. 544)*. The above enlarged cells (called gonidia) of the mother-colony, after retracting their

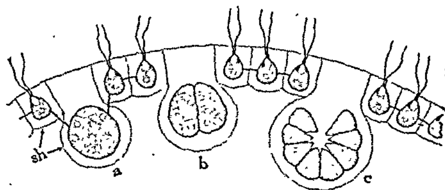


FIG. 544

Volvox: Asexual Reproduction. *Fig.* 544. Formation of a daughter colony within a mother colony; a, an enlarged vegetative cell (gonidium); b, the same after first division; c, a young daughter colony developed from it; sh, sheath.

cilia and pushing back to the posterior side, divide and
divide in the longitudinal plane and give rise to a
number of cells in one plane, thus forming new young daught

colonies within the mother-colony. When cell-divisions cease the cells turn round, develop cilia and form again hollow spheres. These are seen to float and slowly revolve within the much enlarged hollow portion of the mother-colony. Soon they escape from their imprisoned state by a rupture of the membrane of the mother-colony or through a pore in it, and swim away as independent colonies.

Sexual Reproduction (figs. 545-6). Sexual reproduction is oogamous in *Volvox*. In the monoecious species both types of gametes (male and female) are borne by the same colony (*homothallic*), while in the dioecious species these are borne by separate colonies (*heterothallic*). The said gametes are

Fig. 545

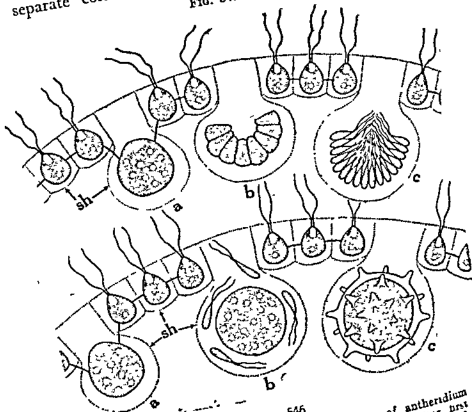


Fig. 546

Volvox: Sexual Reproduction. Fig. 545. Formation of antheridium and antherozoids; a, an antheridium; b, the protoplast of it after first few divisions; c, antherozoids formed in a cluster, sh, sheath. Fig. 546 Formation of oogonium, egg and zygote; a, a young oogonium (the whole protoplast of it is an egg); b, the egg about to be fertilized (note the antherozoids surrounding it); c, zygote formed after fertilization; sh, sheath.

borne by certain enlarged cells called gametangia (gamete-bearing cells) which lie in the posterior side of the colony.

Some of these cells are antheridia or male reproductive organs, the protoplast of which divides many times and produces a cluster of minute biciliated male gametes called antherozoids or sperms (fig. 545); while other cells are oogonia or female reproductive organs, the protoplast of which forms a single large female gamete called egg or ovum (fig. 546). The egg is large passive and non-motile, while the sperms are very minute active and motile. The latter may be in a plate-like colony escaping from the mother-colony as a unit, or these may be arranged to form a hollow sphere. In the former case the unit as it approaches an egg breaks up into individual sperms, and in the latter case the sperms are liberated singly. The mode of fertilization is oogamous. The sperms swim and enter through the gelatinous sheath into the oogonium lying in the mother-colony, and one of them finally fuses with the egg (fig. 546). Thus fertilization is effected.

Zygote. After fertilization the zygote clothes itself with a thick spiny wall and turns orange-red (fig. 546c). It is set free from the mother-colony only after the decay or disintegration of the latter. The zygote sinks to the bottom of the pool of water, and then after a period of rest it germinates with the approach of the favourable season. The protoplast of the zygote undergoes reduction division prior to germination. In some species the protoplast of the zygote divides and forms a new colony directly, while in others it forms a single biciliated zoospore which escapes by the rupture of the zygote wall and swims away. The free-swimming zoospore then divides and forms a new colony.

4. *ULOTHRIX* (30 sp.)

Ulothrix (fig. 547) is a green filamentous alga occurring in fresh water in pond, ditch, water-reservoir, horse- or cow-trough, slow streams, etc., particularly in the spring; a few species grow in the sea. The *filament* of *Ulothrix* is unbranched and consists of a single row of more or less rectangular cells. It is fixed to the substratum or to any hard object in water by the basal elongated colourless cell called *holdfast*. The filament, if detached, may freely float on water. Each cell of the filament contains a nucleus and a peripheral band-like chloroplast with entire or lobed margin. Usually there are many (sometimes one or few) *pyrenoids* lying embedded in the chloroplast. These are rounded protein bodies with a starchy envelope.

Reproduction takes place asexually by zoospores, sexually by gametes, and vegetatively by fragmentation of the filament.

Asexual Reproduction. (1) Zoospores with four cilia (**megazoospores**) are produced for the process of asexual reproduction by division of the protoplast of any cell of the filament except the holdfast. They are larger than the gametes but produced in fewer numbers—2, 4, or 8 or sometimes even 1,

Ulothrix. FIG. 547. Life-cycle: sexual reproduction—A, vegetative filament; B, formation of gametes; C, gametes swimming; *D-G*, stages in the conjugation of gametes; H, zygospore; I, the germ-plant with zoospores; J, a zoospore (quadriciliated); K, a young filament; asexual reproduction—*B*, a portion of the filament showing the formation of zoospores; *C*, a quadriciliated zoospore; *D*, zoospores swimming; *E*, a zoospore rounded off; *F*, zoospore germinating; and *G*, a young filament.

rarely as many as 16 or even 32—in each cell. Each zoospore is more or less pear-shaped and contains a distinct red *eye spot* on one side, a pulsating vacuole close to the flagellate end, and a large chloroplast. The zoospores escape by an opening in the lateral wall of the cell and briskly swim about in water for some hours or even for a few days. Then they come to rest and attach themselves to any hard object in water by their colourless end. Cilia are withdrawn and a cell-wall is formed round each zoospore. Then it germinates directly into a new

filament. (2) Sometimes smaller zoospores (but bigger than gametes), called **microzoospores,** *are produced in the filament,* and they possess either two cilia or four cilia. They either germinate directly into new *Ulothrix* filaments like the zoospores, or they fuse in pairs like the gametes. This indicates that the origin of gametes lies in zoospores. (3) Sometimes the whole protoplast of a cell may round itself off and form a thick-walled spore known as the **aplanospore** (non-ciliated, non-motile, modified zoospore).

Sexual Reproduction. Sexual reproduction is isogamous consisting in the fusion of two similar biciliated gametes (*isogametes*). The gametes may be formed in any cell of the filament except the holdfast. They are smaller than the zoospores, biciliated and may be 8, 16, 32 or 64 in number in each cell. Each gamete possesses a red *eye spot* and a chloroplast band. The gametes are set free from the cell exactly in the same way as the zoospores and they swim about in water with the help of their cilia for some time. Two gametes coming from two different filaments (*heterothallic*) get entangled by *their cilia and gradually a complete fusion (conjugation) of* the two takes place laterally. Cilia are withdrawn towards the close of the process, and the fusion product still moves for a while but soon comes to rest. It rounds itself off and clothes itself with a thick cell-wall, and forms into a **zygospore.** After a period of rest the zygospore germinates into a unicellular *germ-plant* which produces zoospores or aplanospores—4 to 16 in number. They are quadriciliated (zoospores) or non-ciliated (aplanospores) and each develops into a new plant. If fusion fails, each gamete may behave as a zoospore. It withdraws the cilia, rounds itself off and clothes itself with a cell-wall. After a dormant period it directly germinates into a new *Ulothrix* filament. The zygote nucleus has $2n$ or *diploid* chromosomes. It undergoes reduction division and the zoospores are provided with n or *haploid* chromosomes. This haploid number continues throughout the life of *Ulothrix* plant.

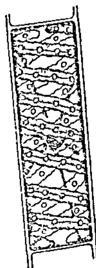
Vegetative Reproduction. This takes place by **fragmentation** of the filament into short pieces, each consisting of a few cells. Each piece or fragment grows into a long filament by transverse divisions of cells and their enlargement.

Note. In *Ulothrix* we get a very early indication of sexual differentiation which becomes so pronounced in the higher plants. The behaviour of gametes or sexual cells and zoospores o [illegible]
former were originally derived from the [illegible]
appearance, but not so in their behaviour.

as the egg-cell or female gamete, and the active one as the male gamete. *Ulothrix* thus shows the beginning of sexual differentiation.

5. *SPIROGYRA* (100 sp.)

Occurrence. *Spirogyra* (fig. 548) is a green filamentous alga occurring in a tangled mass which is seen to float about freely in water. It is a cosmopolitan plant of fresh water, and is found growing abundantly in ponds, ditches, springs, slow-running streams, etc. In some species growing in running water a short unicellular organ of attachment, called *haptera*, is however, formed.

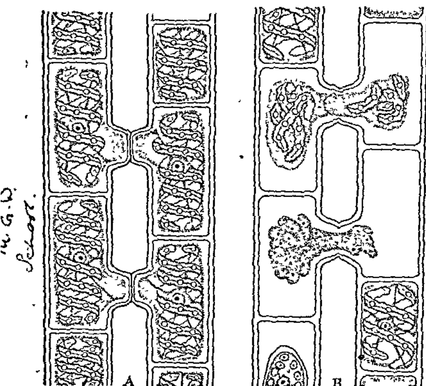


Spirogyla. FIG. 548. A cell of the filament showing two spiral bands of chloroplasts with pyrenoids, and a nucleus suspended by delicate strands of protoplasm.

Structure. Each *Spirogyra* plant is an unbranched filament, a few inches in length, consisting of a single row of cylindrical cells. The walls are made of cellulose and pectin. Pectin swells in water into a gelatinous sheath, and the *Spirogyra* filament becomes invested by this sheath. It is, therefore, slimy to touch. The filament shows no differentiation into the base and the apex. Each cell has a lining layer of protoplasm in which one or usually more *spiral bands* of chloroplasts—the characteristic feature of *Spirogyra*—lie embedded. The nucleus is situated somewhere in the centre suspended by delicate strands of protoplasm, and there is one large central vacuole. Chloroplasts vary in number from 1 to 14 in each cell, and run along the whole length of the cell. The margin of each chloroplast may be quite smooth or wavy or serrated. It includes in its body a number of nodular protoplasmic bodies, known as *pyrenoids*. Pyrenoids are connected by a sort of ridge which develops on the inner side of the chloroplast, and around them minute starch grains are deposited. There is usually one large nucleolus in each nucleus, but frequently more. Growth by elongation and cell-division by mitosis usually take place at night. If the filament happens to be broken up into individual cells or into short pieces, the cells divide and give rise to new filaments (vegetative propagation).

Reproduction. This takes place in *Spirogyra* by the sexual method. This consists in the fusion of two similar reproduc-

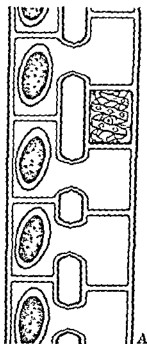
tive units or gametes. The fusion of two similar gametes, i.e. isogametes (see p. 369), is known as **conjugation**. Conjugation usually takes place between the cells of two filaments or even three; this is called scalariform (or ladder-like) conjugation. Sometimes, however, conjugation takes place between the cells of the same filament; this is called lateral conjugation. **Scalariform conjugation** (fig. 549). When two filaments come to lie in contact in the parallel direction they repel each other.



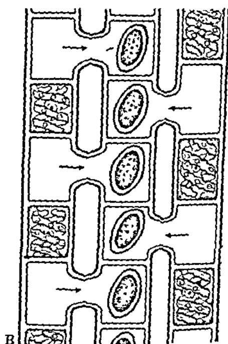
Spirogyra. FIG. 549. Scalariform conjugation, *A-B* are stages in the process.

As a result of this repulsion tubular outgrowths develop from the opposite or corresponding points of contact of the two filaments. These tubular outgrowths are called **conjugation tubes**, and when all or most of the cells of the two filaments have formed such tubes the whole structure looks more or less like a ladder and hence the name scalariform or ladder-like conjugation. Their end- or partition-walls dissolve and an open conjugation tube is formed. In the meantime the protoplasmic contents of each cell lose water, contract and become rounded off in the centre. Every contracted mass of protoplasm forms a gamete. All gametes are alike in appear-

ance and, therefore, they are known as *isogametes*. By a sort

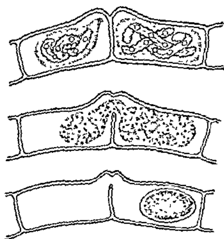


Spirogyra. FIG. 550. Formation of zygospores after conjugation.



Spirogyra. FIG. 551. Scalariform conjugation between three filaments.

of *amoeboid* movement the gametes of one filament creep through the conjugation tubes into the corresponding cells of the adjoining filament and fuse with the gametes of that filament. *The fusion of two gametes* results in the formation of a zygote. The zygote clothes itself with a thick wall, and is known as the ***zygospore*** (fig. 550). In some cases the gametes may fuse in the conjugating tubes. The wall of the zygospore is thick and black or brownish-black. It is to be noted that the gametes of one filament always pass on to the gametes of the other filament. Thus one filament becomes practically empty except for a few vege



Spirogyra. FIG. 552. Lateral conjugation and formation of zygospore.

tative cells here and there; while the other one is provided with a row of zygospores. Sometimes it is seen that three filaments are involved in the process of conjugation, zygospores being formed in the middle filament (fig. 551). **Lateral conjugation** (fig. 552). This takes place between the cells of the same filament. An outgrowth or conjugation tube is formed on one side of the partition wall, and through the passage, thus formed, the gamete of one cell passes into the neighbouring cell. Instead of conjugation tube an opening may be formed in the partition wall through which the gamete may pass. In lateral conjugation the gametes of alternate cells only move to the neighbouring cells, and thus later on zygote-bearing cells are seen to alternate with empty cells in the same filament.



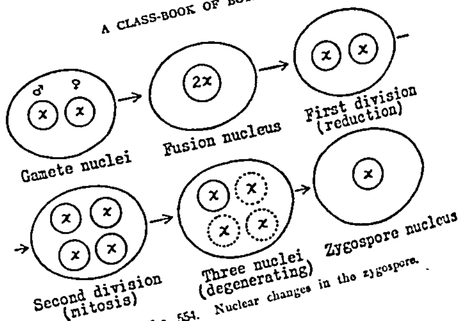
Spirogyra. FIG. 553 Zygespore germinating.

Sometimes it so happens that conjugation does not take place, and then the gametes become directly converted into spores. Spores of this kind are called **azygospores.** The process is parthenogenetic (see p. 371). They germinate like the zygospores.

Note. In *Spirogyra* there is no distinction between male and female gametes so far as their shape and structure are concerned, but there is some difference in [illegible] e and initiative and may be regarded a [illegible] non-motile and receptive and may be [illegible] the cells of one filament behave as ma[illegible] It is also seen that the chloroplasts of [illegible], while those of the female gamete persist as broken filaments.

Germination of Zygospore (fig. 553). The zygospore is provided with a thick cellulose-wall, composed of three layers, of which the middle one contains some chitin. It sinks to the bottom of the tank or the water in which it is growing. It undergoes a period of rest and then germinates. The protoplast of the zygospore at first increases in size; then its outer walls burst and the inner wall with the protoplast grows out in the form of a short tube which ultimately forms into a new filament. The filament escapes and floats on the surface of water. Cells divide and the filament increases in length [Life-cycle of *Spirogyra* is depicted in fig. 555].

Reduction Division (fig. 554). It is to be noted that the zygote is formed as a result of fusion of two gametes, each with n (or x) chromosomes and, therefore, the zygote nucleus has $2n$ (or $2x$) chromosomes. The nucleus of the zygote at first undergoes a reduction division, the resulting nuclei divide again so as to form four nuclei, each with n (or x) chromosomes. Three of these nuclei degenerate so that the mature zygote contains a single nucleus with n (or x) chromosomes.



Spirogyra. FIG. 554. Nuclear changes in the zygospore.

FIG. 555. Life-cycle of *Spirogyra*. *A*, a vegetative filament [illegible]

6. *OEDOGONIUM* (300 sp.)

Vegetative Structure. *Oedogonium* (fig. 556) is a common green alga living in fresh water. Each plant is an unbranched filament consisting of a row of elongated cells. Filaments usually remain attached to any object by an irregularly lobed basal cell, called the *holdfast*. Older filaments may float freely on water. The apex of the filament may be rounded or may end in a hair-like structure. Growth takes place by cell-division and may be apical or intercalary. Ring-like markings are often formed in the upper part of the cell. Each cell contains a single nucleus and a single large peripheral chloroplast which takes the form of a network lining the cell-wall. Pyrenoids are present.

Asexual Reproduction (fig. 557). This method of reproduction takes place by zoospore. Any cell of the filament may form a single zoospore by the process of **rejuvenescence** (see p. 210). The contents of the cell become rounded off and form a **zoospore.** It is a large pear-shaped body. Its narrower end is clear and bears a ring of cilia; while its broader end is green containing a chloroplast. The zoospore escapes by transverse splitting of the upper wall of the cell, swims in water for a while and then gets attached to some object. All the cilia are withdrawn; it then clothes itself with a cell-wall and eventually germinates into a filament.

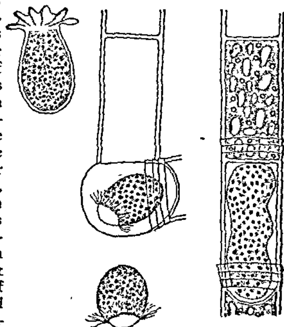


FIG. 556 FIG. 557

Oedogonium: Asexual Reproduction. Fig. 556. A portion of a filament showing a chloroplast and a zoospore in the process of formation. Fig. 557. Zoospore escaping; *top*, zoospore swimming; *right*, zoospore attached to an object.

Sexual Reproduction (figs. 558-60). Sexual reproduction takes place by differentiated male and female gametes, known respectively as antherozoid and oos-

phere or egg-cell. Many species are monoecious (*homothallic*), and some dioecious (*heterothallic*). Antherozoids are borne in certain small cells, known as **antheridia** (fig. 558). The latter are produced in a series by repeated divisions of any cell of the filament. The protoplasmic contents of each antheridium divide once and produce a pair of **antherozoids.** Each antherozoid is furnished with a ring of cilia and is like the zoospore, excepting that it is smaller in size. Antherozoids are liberated by a transverse slit of the antheridial wall.

The female gamete or oosphere is borne in a large spherical cell, known as the **oogonium** (fig. 559). Oogonia occur amongst the ordinary vegetative cells of the filament, either singly or 2 or more together. The protoplasmic contents of the oogonium withdraw from the cell-wall and form a single large egg-cell or oosphere. There is a colourless spot—the receptive spot—at one end of the oosphere, and close to this spot the oogonium opens by a pore or a transverse slit of the wall.

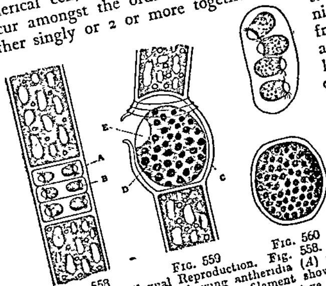
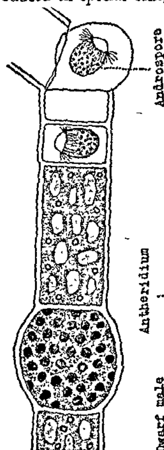


Fig. 558 Fig. 559 Fig. 560

Oedogonium: Sexual Reproduction. Fig. 558. A portion of a filament showing antheridia (*A*) and antherozoids (*B*). Fig. 559. A filament showing oogonium (*C*) and egg-cell (*D*) with receptive spot (*E*). Fig. 560. *Bottom*, an oospore; *top*, formation of zoospores from it.

Fertilization. When the antherozoids are liberated they swim to the oogonium with the help of their cilia. Then one antherozoid enters through the slit in the oogonium wall and fuses with the oosphere at the receptive spot (fig. 559E). The oosphere then covers itself with a cell-wall and becomes a reddish-brown **oospore** (fig. 560 *bottom*). The oospore sinks to the bottom, undergoes a period of rest and then germinates. The nucleus of the oospore has $2n$ chromosomes, being the product of fusion of two gametes, each with n chromosomes. It undergoes reduction division giving rise to four **zoospores** (fig. 560 *top*), each of which is provided with n chromosomes. The zoospores escape and swim about for some time. Then they rest for a while, attach themselves to some object, and each germinates into a new filament.

In some species of *Oedogonium* a complicated process of reproduction takes place. In them a special type of zoospores, called **androspores** (fig. 561), is produced by the same filament that bears the oogonia or by a distinct filament. Androspores are produced in special cells, called **androsporangia**, which are



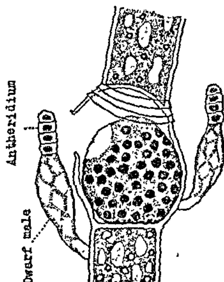


Fig. 561 Fig. 562

Oedogonium. Fig. 561. A portion of a filament showing an oogonium and two androspores. Fig. 562. A filament showing oogonium with a receptive spot and two dwarf males attached to it.

formed either singly or in a row like the antheridia by division of the ordinary vegetative cells of the filament. Each androsporangium produces a single androspore which like the antherozoid is provided with a crown of cilia and is motile. The androspore is intermediate in size between the zoospore and the antherozoid. When liberated, the androspore swims for a while and soon attaches itself direct to the oogonium or to a cell close to it. It then produces a short narrow ... called *dwarf male* (fig. 562), consisting of an elongated ba... cell and a terminal cell or sometimes a row of cells ...

2 to 4). Each such cell is an antheridium. It bears a pair of small motile antherozoids crowned with cilia. The antheridium opens by a lid at the apex or it ruptures by the wall and the antherozoids are liberated. They swim to the oogonium and fertilization takes place in the way described above.

7. *VAUCHERIA* (35 sp.)

Occurrence. *Vaucheria* (fig. 563) is a green alga of fresh water, growing with other algae in ponds, ditches and also in the wet soil. It is not free-floating like *Spirogyra* but is mostly attached to a substratum by means of colourless rhizoids or 'holdfasts'. It is deep green in colour and always lives in a tangled mass.

Structure. The thallus consists of a single branched tubular filament. It is unseptate, and contains numerous

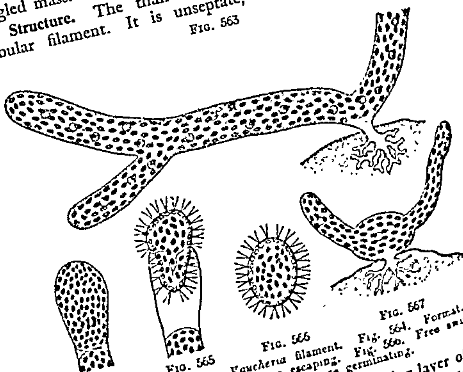


Fig. 563. A *Vaucheria* filament. Fig. 564. Formation of zoosporangium. Fig. 565. Zoospore escaping. Fig. 566. Free swimming zoospore. Fig. 567. Zoospore germinating.

minute nuclei which lie embedded in the lining layer of cytoplasm surrounding a large central vacuole. Such a structure is known as a coenocyte; *Vaucheria* is, therefore, a coenocyte. Septa, however, normally appear in connexion with the reproductive organs. Injury also results in the production of septa cutting off the injured parts which then develop into new plants. Filaments increase in length by apical growth. Chloroplasts are numerous, very small and discoidal in sha-

They lie embedded in the lining layer of protoplasm, and are without pyrenoids. Protoplasm contains abundant oil-globules, but lacks in starch.

Reproduction. This takes place asexually as well as sexually.

Asexual Reproduction. This takes place by a large solitary **zoospore.** During its development the apex of the filament swells up, becomes club-shaped and is partitioned from the rest of the filament by a septum. This club-shaped body is known as the **zoosporangium** (fig. 564). Its protoplasmic contents then become rounded off forming a single **zoospore** and escape as such through a narrow apical opening (fig. 565). The zoospore (fig. 566) is an oval body of large size. The central part of it is occupied by a large vacuole, and in the surrounding zone of protoplasm there lie embedded numerous small chloroplasts, giving the zoospore an intensely deep green colour. The whole surface of the naked (without cell-wall) zoospore is *covered with numerous short cilia arranged in pairs ; under* each pair there lies a nucleus. The zoospores generally escape in the morning. They swim about freely in water for a while (half an hour or less) by the vibration of their cilia and soon come to rest. The cilia are immediately withdrawn and a cell-wall is developed round them. After coming to rest the zoospores germinate (fig. 567) almost immediately by the protrusion of one or more tube-like filaments, one of which, at least, produces a colourless branched rhizoid, and attaches the plant to the substratum. The protoplasm leaves the old cell and rejuvenates, i.e. it becomes young and active ; this method of asexual reproduction is known as **rejuvenescence.**

Sexual Reproduction. This takes place by the method of **fertilization,** that is, by sharply differentiated male and female organs. Male organs are known as **antheridia** (sing. antheridium) and female organs as **oogonia** (sing. oogonium), and these are developed at scattered intervals as lateral outgrowths. In monoecious species of *Vaucheria* antheridia and oogonia usually arise side by side on the same filament (figs. 569-70) or on short lateral branches of it (fig. 568).

The outgrowth that forms the **oogonium** swells out, assumes a more or less rounded form, and is cut off by a basal septum (figs. 568-70). The apex of the oogonium generally develops a *beak,* either towards the antheridium or away from it.. The protoplasm of the oogonium contains much oil, *numerous chloroplasts, but only one nucleus.* There is a single large female gamete, i.e. the **egg-cell** (ovum or oosphere), which completely fills the oogonium. The oogonium is at

first multinucleate, but before the partition wall is formed all the nuclei except one return to the main filament.

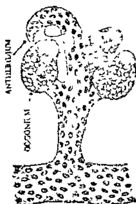


Fig 568

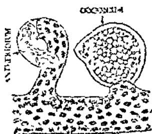


Fig. 569

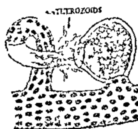


Fig. 570

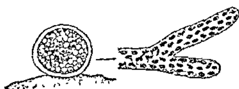


Fig. 571

Vaucheria. Fig. 568. Antheridium and oogonia on a short lateral branch. Fig. 569. The same borne directly by the filament. Fig. 570. Mature antheridium and oogonium; antherozoids discharged and ovum about to be fertilized. Fig. 571. Oospore and a new filament developed from the oospore

Each **antheridium** arises as a short tubular branch by the side of the oogonium, and simultaneously with it. The terminal portion of it is cut off by a septum, and then it becomes the actual antheridium (figs. 568-70). As it matures it usually becomes much curved towards the oogonium. The protoplasm contains numerous chloroplasts and nuclei. Numerous male reproductive units or male gametes, known as **antherozoids**, are produced inside each antheridium. They are very minute in size and are biciliated. The cilia point in opposite directions.

Fertilization. Self-fertilization is the rule, but in dioecious species cross-fertilization is apparent. The antheridium bursts at the apex and the antherozoids swarm in the vicinity of the oogonium, the beak of which opens at the same time (fig. 570). Only one antherozoid enters through the beak and fuses with the oosphere, while the rest perish. Thus fertilization is effected. After fertilization the oosphere becomes invested with a thick cell-wall, and is known as the **oospore** (fig. 571). The oospore undergoes a period of rest and then it germinates directly into a new *Vaucheria* filament. Reduction division has not yet been observed in *Vaucheria*.

CHAPTER III

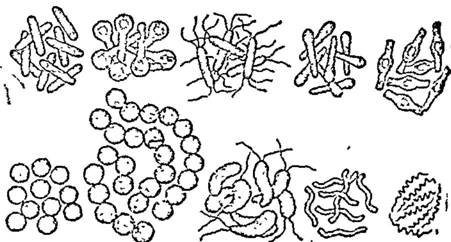
BACTERIA (SCHIZOMYCETES)

A short Historical Account. Antoni von Leeuwenhoek (1632-1723) of Delft in Holland was the first to discover bacteria (1653-1673) with the help of the microscope invented and considerably improved by himself (see also p. 171) Louis Pasteur (1831-1895) of France thoroughly established the science of bacteriology. He carried on extensive work on fermentation and decay, and the cause of hydrophobia About the year 1876 Pasteur made known to the world the importance of bacteria He was the first to prepare vaccine and use it for the cure of the disease. He saved many Russians from hydrophobia by the use of this vaccine, and the Tsar of Russia in honour of his marvellous discovery sent him a diamond cross and also a hundred thousand francs to build a laboratory in Paris—now called the Pasteur Institute About the same year Robert Koch of Germany proved that anthrax disease so common in cattle was caused by a kind of bacteria. He also showed in 1882 that tuberculosis and Asiatic cholera were caused by bacteria. From that time onwards many workers came into the realm of this new science. Prominent among them were Emile Roux—helper of Pasteur, and Emil Behring—pupil of Koch who discovered diphtheria anti-toxin about the year 1894; Elie Metchnikoff of South Russia in the eighties of the last century proved that phagocytes eat up germs and protect the body; Theobald Smith of America discovered in 1893 germs of Texas fever in the blood corpuscles of cows; in 1898 Ronald Ross, an officer in the Indian Medical Service, after a prolonged and laborious research in different parts of India, discovered that a particular kind of gray mosquito was the cause of malaria. He was a recipient of the Nobel prize In the same year Battista Grassik, an Italian, also discovered that the gray mosquito (*Anopheles claviger*) carried malaria germs, but he was not so well known as Ronald Ross. In the early part of the present century Walter Reed discovered in America that yellow fever was caused by a kind of mosquito.

General Characteristics. Bacteria (Schizomycetes) are the smallest and the most primitive organisms known to us, and number about 1,500 species. Most of them are single-celled—usually spherical, rod-like or branched. Many of these micro-organisms are as small as 1 micron or even ·5 micron, particularly the spherical ones, while the rod-like or filamentous forms may be ·10 microns in length or even much longer (1 micron=1/1,000 mm. or about 1/25,000 inch). Being so minute in size they are imperfectly seen even at the highest magnification of the microscope.

They occur almost everywhere—in water, air and soil, and in foodstuff, fruits and vegetables. Many of them float in the air; many are abundant in water; and many are specially abundant in the soil, particularly to a depth of one foot, and also in sewage. A few thousands of them may occur in 1 c.c. of water, and a few millions in 1 gram of soil. Many live within and upon the bodies of living plants and animals. The intestines of all animals always contain a good number of different kinds of bacteria.

Bacteria are mostly unicellular but are of various shapes and sizes. Some of them change their shapes under different conditions and as such escape easy detection. In many cases the cells may adhere together into a small group or into a chain or into a filament—branched or unbranched. Each cell although extremely minute in size and simple in structure is complete by itself carrying on all the vital functions. It consists of a speck of protoplasm surrounded by a cell-wall made of chitin which contains nitrogen, sometimes enclosed in a sheath. There is no definite nucleus which in many cases is represented by chromatin granules only. The stainable chromatin may be confined to one part of the cell forming an incipient nucleus or may be scattered throughout the body. Many forms are provided with 1 or more cilia (or flagella) for motility of these organisms. Bacteria are, however, altogether devoid of chlorophyll although there may be other colouring matters present in them. This being so, they lead either a saprophytic or parasitic life. There are, however, a few bacteria which are autotrophic (see p. 424).



Bacteria. Bacilli: Fig. 572. *Bacillus tuberculosis.* Fig. 573. *B. tetani.* Fig. 574. *B. typhi.* Fig. 575. *B. diphtheriae.* Fig. 576. *B. anthracis.* Cocci: Fig. 577. *Staphylococcus.* Fig. 578. *Streptococcus.* Comma: Fig. 579. *Vibrio cholerae.* Spirilla: Fig. 580. *Spirillum* (common in water). Fig. 581. *Spirochaete.*

Reproduction. There is no sexual mode of reproduction in bacteria. The individual cells may divide, often repeatedly, and multiply in number. Some of the bacteria may reproduce by spore formation but by this method they cannot multiply in number.

1. *By Fission.* Many bacteria divide by the process of fission (see p. 367). A constriction appears around the middle of the cell and it becomes split up into two parts. These parts grow in size and form mature bacterial cells. Fission may take place in 1 plane or in 2 or 3 planes. In the first case chains of cells may appear; in the second case a plate-like structure may be formed; and in the third case a colonial structure may be the result. The rate of multiplication depends on the species as well as on the surrounding conditions. Hay bacillus (*Bacillus subtilis*), for instance, divides 2 or 3 times an hour under favourable conditions. At the minimum rate of division a single cell may give rise to over sixteen million (16,777,216) offspring at the end of 12 hours.

2. *By Spore Formation* (fig. 582). Some bacteria form spores which are always 'resting' spores. The special advantage of the spores is that they can withstand very unfavourable conditions such as high temperature, freezing, extreme dryness, presence of many poisonous chemicals. A portion of the protoplasm aggregates into a small mass in any part of the cell and clothes itself with a thick membrane, forming an *endospore* within the mother-cell which soon dissolves. The endospore may remain dormant for months or even several years resisting adverse conditions of life. Then in a suitable medium under favourable conditions of moisture and temperature the endospore enlarges, the wall partly disintegrates and the contents form a full-fledged bacterial cell.

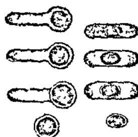


FIG. 582. Spore formation in two types of bacteria.

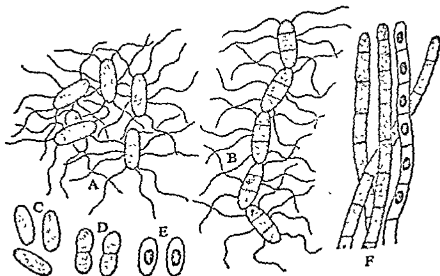
Classification. Unbranched unicellular forms of bacteria may be classified into the following groups: (1) **bacilli** (sing. bacillus)—these are rod-shaped bacteria, e.g. *Bacillus tuberculosis, B. tetani, B. typhi*, etc.;
are spherical bacteria, e.g.
Azotobacter, etc.; (3) **spirilla**
bacteria with the body spirally wound, e.g. *Spirillum, Spirochaete*, etc.; and (4) **commas**—these are slightly twisted like a comma, e.g. *Vibrio cholerae*.

Physiology of Bacteria. Bacteria are lacking in chlorophyll and thus are mostly unable to utilize carbon dioxide for synthesis of organic compounds for their food. They are mostly *heterotrophic* (see p. 320) in habit, leading a saprophy-

tic life or a parasitic life. A small number is, however, *autotrophic* containing a purplish or greenish pigment. Such bacteria are able to manufacture organic food compounds from carbon dioxide and other simple inorganic substances present in the soil. For this purpose they utilize *energy from light* as in the case of green plants, or they secure necessary energy from the oxidation of certain chemical substances.

Saprophytic or Decay Bacteria. These live in media (usually soil and water) containing organic compounds of plant or animal origin and utilize them as food. Some bacteria have a liking for carbohydrates, while others for proteins, fats or amino acids. Most of the common types of saprophytic bacteria, however, act on a variety of organic compounds. Like higher plants bacteria secrete enzymes to bring about digestion of insoluble and complex organic compounds into soluble and simple forms. Many of them are responsible for the decay of dead plants and animals and their products. Thus rotting of vegetables and fruits particularly in storage, fermentation of food, souring of milk, formation of vinegar, etc., are mainly due to bacterial action.

Hay bacillus (*Bacillus subtilis*) is a common form of saprophytic bacteria growing in a decoction of hay. It can be easily grown in the laboratory by soaking hay in water and boiling the same; the spores of hay bacillus withstand prolonged boiling. The decoction may then be kept in a warm place



Hay bacillus (*Bacillus subtilis*). FIG. 585. *A*, motile forms; *B*, a chain of motile forms; *C*, non motile forms; *D*, fission; *E*, spore-formation; and *F*, chains of non-motile forms with spore-formation in one chain.

for a day or two. One or two drops of it may then be examined under a microscope at high magnification. Hay bacillus is unicellular and rod-shaped, provided with a number of flagella all over its body. The cells may

be held together in chains. There is a granular vacuolated mass of protoplasm with chromatin granules but no definite nucleus. While growing in the fluid hay bacillus reproduces by fission. The cell undergoes constriction in the transverse plane and is split up into two. The process of fission may be repeated several times and numerous cells formed within a short time. It is seen that the cells overcrowding the liquid tend to come to the surface. The cells lose their cilia and become non-motile. Their walls become gelatinous and the cells are held together in long chains. Several such chains form a mucilaginous mass, called a *zoogloea*, which floats as a thin film or scum on the surface of the liquid When food is exhausted, the bacillus cells form 1 or 2 spores, called *endospores*, within the mother cell. The protoplasm withdraws from the wall and clothes itself with a fresh firm wall which can resist the action of high temperature and many poisonous substances. Later under favourable conditions the spore germinates in suitable medium. The wall of the mother cell decays and the spore is liberated. The tough coat of the spore splits and the protoplasm escapes into the surrounding water Cilia are formed and the bacillus cell leads an active life.

Parasitic or Pathogenic Bacteria. Many bacteria infect living plants and animals, particularly the latter, and derive organic food compounds from the tissues of the host. Parasitic bacteria, unlike the saprophytic ones, are very exacting in their selection of the host and often a particular part of it, evidently for a particular kind of food. Many of them cause various and often serious diseases in them, sometimes in epidemic form. They are the agents responsible for various kinds of infectious and contagious diseases, and are dreaded as invisible enemy. Normally they infect the host through wounds or these may be breathed in or taken in with food, water and milk. These bacteria may be aerobic or anaërobic. After infection of the body they produce a toxin (poison) and the body in its turn produces an anti-toxin to counteract the toxin. This is the principle of combating bacterial diseases, and the inoculation of the body with anti-toxic serum is the modern method of preventing and treating such diseases. It is seen that a person suffering from a particular disease, e.g. smallpox, becomes immune to it temporarily or sometimes permanently. *This is because of the formation of anti-toxin in* the infected body. Some of the common disease-producing bacteria are: *Bacterium dysenteriae* causing dysentery, *B. influenzae* causing influenza, *B. diphtheriae* causing diphtheria, *B. pneumoniae* causing pneumonia, *B. tuberculosis* causing tuberculosis, *Bacillus typhi* causing typhoid fever, *B. tetani* causing tetanus, etc. Some species of streptococci (the blood-poisoning bacteria) are possibly the deadliest enemy of mankind. They have the remarkable power of dissolving the red corpuscles of the human blood, and are responsible for erysipelas and extremely dangerous kinds of blood-poisoning.

Parasitic bacteria also attack plants and cause various diseases such as blight disease of apple and pear, ring disease

of potato, black rot of cabbage, canker of *Citrus*, and many diseases of fruits and vegetables. In plants, however, fungal diseases are far more common than bacterial diseases, while in animals the reverse is the case.

Autotrophic Bacteria. Some of them obtain energy by the break-down (oxidation) of certain chemical substances and utilize this energy for the manufacture of food substances from carbon dioxide and other inorganic compounds present in the soil; while others utilize energy from light for the same purpose. Thus **sulphur bacteria** oxidize hydrogen sulphide to free hydrogen and then to sulphuric acid which in the soil transforms into sulphate as a source of plant food. The energy thus obtained by oxidation is utilized in the synthesis of organic compounds, as stated above. Similarly **iron bacteria** and **hydrogen bacteria** oxidize iron compounds and molecular hydrogen and utilize energy by these oxidative processes. **Nitrifying bacteria** of two types oxidize ammonia to nitrite and nitrite to nitrate in two stages. **Purplish sulphur bacteria** and **greenish bacteria** on the other hand utilize light energy for the synthesis of organic compounds for their own use; they oxidize sulphuretted hydrogen in the presence of light.

Viruses. There are still smaller organisms than the bacteria, which defy the viruses. Their presence can be made e in the plant body or the animal body. as mumps, smallpox, chicken-pox, measles, yellow fever, scarlet fever, infantile paralysis, influenza, common cold, cancer, hydrophobia, etc., are supposed to be caused by viruses. Among the plants the mosaic disease of potato, tomato, tobacco, gourds, cucumbers, ground nut, etc., the yellow disease of peach, curly top of beet, radish, cabbage, turnip, etc., and necrosis (necrotic disease) of potato and tomato are said to be caused by viruses.

Beneficial Effects of Bacteria. Although some bacteria (the disease-producing ones) are most harmful it is a fact that a large number of them are most useful in various ways, particularly in agriculture and some of the industries. Many bacteria are nature's scavengers.

1. **Agricultural.** (*a*) **Decay of Organic Substances.** But for the most useful work of many bacteria the organic substances contained in the dead bodies of plants and animals and in the huge amount of garbage, would have remained permanently locked up in them apart from the fact that they themselves would have covered the surface of the earth leaving very little room for human beings. As a matter of fact dead bodies of plants and animals are acted on by different kinds of bacteria and the proteins are released from them and made available to green plants in suitable forms. Thus it is seen that in the

absence of oxygen proteins are converted into ammonium compounds (ammonification) and then oxidized into nitrite and nitrate (nitrification) suitable for absorption by the green plants. Carbohydrates are broken up into carbon dioxide and water. (*b*) **Nitrogen Fixation.** Fixation of free nitrogen of the air by many soil bacteria like *Azotobacter* and *Clostridium* directly in their own bodies, and *Rhizobium* (nodule bacteria) in association with the roots of leguminous plants is very important from an agricultural standpoint. (*c*) **Fertilizers.** Conversion of cowdung, animal excreta into manures, and formation of humus or leaf-mould are due to bacterial activities. Many chemical changes in the soil making it fertile are largely due to the activity of bacteria (and also of many other organisms in the soil). In fact the fertility of the soil may to a very great extent be attributed to the presence of bacteria in it.

2. **Industrial.** From an industrial standpoint also many bacteria are most useful. Curing and ripening of tobacco leaves, fermentation of tea leaves, ripening of cheese, etc., for their characteristic flavours, retting of fibres, formation of vinegar from alcohol by acetic acid bacteria (*Mycoderma*), fermentation of sugar into alcohol by yeast and a few bacteria, curdling of milk by lactic acid bacteria and such other cases of fermentation are specially important.

3. **Medical.** We are normally protected against virulent germs by many of the good bacteria which have been living as a permanent flora in different parts of our body since our childhood. Thus different and distinct types of such bacteria have formed their permanent abode in the mouth, respiratory tract, intestines, etc., and are guarding these passages against invasion by the disease-producing germs by waging chemical warfare against them, saving us from falling a prey to such deadly types. They kill the foreign invading germs by secreting from their body certain specific chemical poisons—the antibiotics.

ymbiotic bacteria

CHAPTER IV

FUNGI

Classification of Fungi (90,000 sp.)

I Myxomycetes or slime fungi (400 sp.).

II Phycomycetes or alga-like fungi (1,000 sp.). Sub-class Zygomycetes (reproduction isogamous), e.g. *Mucor* and *Rhizopus* (moulds). Sub-class Oomycetes (reproduction oogamous), e.g. *Pythium* and *Phytophthora*.

III Ascomycetes or sac fungi (25,000 sp.), e.g. *Saccharomyces* (yeast), *Penicillium* (blue green mould) and *Peziza* (cup fungus).

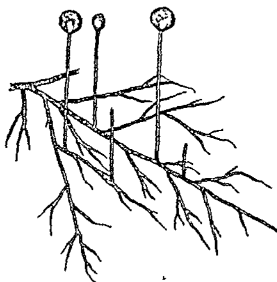
IV Basidiomycetes or club fungi (23,000 sp.), e.g. *Ustilago* (smut), *Puccinia* (rust), *Agaricus* (mushroom) and *Polyporus* (pore fungus).

V Fungi Imperfecti (over 24,000 sp.)—fungi with imperfect life-history.

1. MUCOR (50 sp.)

Occurrence. *Mucor*, commonly called 'pin-mould', is a saprophytic fungus. It grows on horse-dung, wet shoes, stale moist bread, rotten fruits, shed flowers and other organic media, spreading like a cobweb. It can be easily grown in the laboratory in a piece of moist bread kept under a bell-jar in a warm place for 3 or 4 days.

Structure. The plant body is composed of a mass of white, delicate, cottony threads collectively known as the **mycelium** (fig. 584). It is always very much branched, but is unseptate and coenocytic. Each individual thread of the mycelium is known as the **hypha** (pl. hyphae). Cytoplasm of the hypha contains numerous minute nuclei, numerous vacuoles often filled with sugars, glycogen and droplets of fats and oils, but not starch.



Mucor. FIG. 584. Ramifying mycelia with some sporangia (or gonidangia)

Reproduction. This takes place by two methods, viz. (1) asexual and (2) sexual.

Asexual Method. This method of reproduction takes place by means of **spores** (or gonidia) which develop in a case, called *sporangium* (or gonidangium), under

favourable conditions of moisture and temperature. It is seen that mycelia give off here and there numerous hyphae which rise straight up into the air. The apical portion of each of these hyphae *swells* out into a spherical head (fig. 585). As the hypha begins to swell the protoplasmic contents migrate to its tip, but they accumulate more densely towards the periphery, the central part remaining comparatively thin and

Mucor. Fig. 585. Development of sporangium, spores and columella; *A*, the end of the hypha swells; *B*, two regions—dense and light—are apparent with a layer of vacuoles between them; and *C*, mature sporangium (or gonidangium) with spores (or gonidia) and dome-shaped columella.

vacuolate. Later a row of vacuoles is formed around the central part and these soon fuse up. Consequently a cleft is formed between the outer denser portion and the inner thinner portion, thus separating the two portions. The central portion which is dome-shaped and sterile, i.e. without spores, is called the columella. The peripheral protoplasm now gives rise to a number of small, multinucleated, angular masses by cleavage. Each multinucleated mass becomes rounded off and covered by a wall forming a spore. Its wall thickens and darkens. The wall of the sporangium is thin and brittle. Finally as the columella swells due to accumulation of a quantity of fluid in it, it exerts a considerable pressure on the wall of the sporangium which as a consequence bursts, setting free the spores. The spores are blown about by the wind. The columella persists for some time after the bursting of the sporangium. The spores being very minute, light and dry float about in the air, and under favourable conditions they germinate in suitable medium directly into the Mucor plant. Sometimes [illegible] develop from the columella when the sporangiophore [illegible] erect sporangial hypha) happens to fall over and these [illegible] then bear the sporangia.

Sexual Method. Sexual reproduction takes place [illegible] method of conjugation [illegible] under certain [illegible] particularly when the food supply becomes [illegible] jugation consists in the fusion of two similar [illegible]

isogametes (cf. *Spirogyra*). The process is as follows: when two hyphae borne by two different plants of opposite sexes (called the + strain and the – strain) come close together, two short swollen protuberances, called the conjugating tubes or *progametes* (see figs. 586A-B and 588) develop forming a contact at their tips. As they elongate they push the parent hyphae apart from each other. Each progamete enlarges and becomes club-shaped. Soon it is divided by a partition wall into a

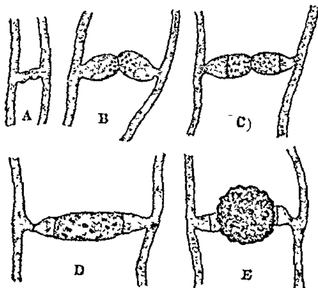


Fig. 586

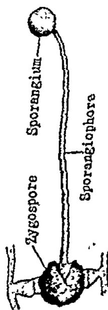


Fig. 587

Mucor. Fig. 586. Conjugation: *A-E* are stages in the process; note the thick-walled zygospore at *E*. Fig. 587. Germination of zygospore.

basal *suspensor* and a terminal *gametangium* (fig. 586C). The protoplasmic contents of each gametangium constitute the gamete. The gametes are multinucleate and are called *coenogametes*. The two gametes are identical in all respects. The end- (or common) walls of the two gametangia get dissolved and the two gametes fuse together (fig. 586D) and form a zygospore (fig. 586E). The zygospore swells into a rounded body, and its wall thickens, turns black in colour and becomes warted. It contains an abundance of food, particularly fat globules.

It has been observed that sometimes no sexual reproduction takes place even though the fungus grows under all favourable conditions. Investigations of the American botanist, Blakeslee (1903), have revealed the fact that there are two different strains or races of the fungus (the + strain and the – strain) and that sexual reproduction only takes place between the hyphae of these two different strains, apparently of opposite sexes. Evidently these two strains formed from separate spores—some giving rise to the plus strains and the others to the minus strains—must grow together.

Morphologically there is no difference between these two strains, excepting that the + strain (regarded as female) shows a little more vigorous growth than the − strain (regarded as male), but physiologically they are different behaving as two opposite sexes. Such species are said to be **heterothallic.** There are, however, many species which form zygote by the conjugation of the hyphae of the same mycelium. Such species are said to be **homothallic.**

Sometimes it so happens that although the conjugating hyphae meet, no fusion of gametes takes place. These then develop into thick-walled spores, called **azygospores.** Sometimes the free end of a hypha may produce a solitary azygospore. Germination of the azygospore has not been followed.

Germination of Zygospore (fig. 587). The zygospore undergoes a period of rest and then it germinates. The outer wall bursts and the inner wall grows out into a tube, called the **sporangiophore or promycelium,** which ends in a single sporan-

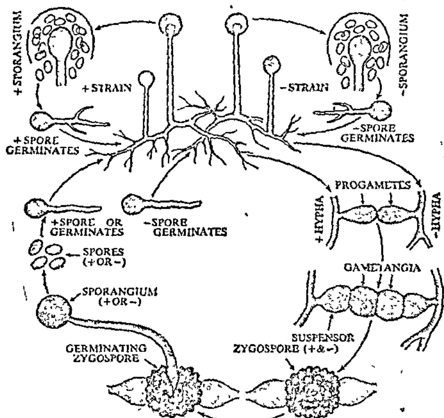


FIG. 588. Life-cycle of *Mucor*.

gium. The sporangiophore may be branched, each branch bearing a sporangium. The sporangium contains numerous small spores but no columella. The spore germinates, giving rise to the *Mucor* plant.

Blakeslee further found that in heterothallic species *all the spores of a sporangium give rise to either + mycelia or to − mycelia, but not both.* The zygote is diploid and contains material of both the + strain and the − strain. It undergoes reduction division at the initial stages of its germination, and segregation of the two strains (+ and −) takes place before the formation of the spores so that all the spores of a sporangium are haploid and are either all + or all −. Thus a single sporangium produces spores of one kind.

Torula condition (*torula*, a small swelling). It is sometimes seen that under favourable conditions the mycelium of *Mucor* becomes segmented into a short chain of cells. These cells then swell up, becoming thick-walled and large (chlamydospores), or they remain thin-walled and small (oidium cells). Chlamydospores are resting spores and they germinate normally giving rise to the mycelium; but oidium cells separate from each other, multiply by budding like the yeast cells, and, like the latter again, set up alcoholic fermentation; the formation of oidium cells and their activity take place specially when the hyphae are immersed in a nutritive liquid.

COMPARATIVE STUDY OF *SPIROGYRA* AND *MUCOR*

Habit and Habitat. *Spirogyra* is a green alga floating in stagnant water, while *Mucor* is a saprophytic fungus growing in horse-dung, stale bread, wet shoes, rotting fruits and vegetables, etc.

Structure. Each *Spirogyra* plant is a slender unbranched filament consisting of a row of cylindrical cells; while *Mucor* consists of a mycelium of delicate white much-branched cottony threads (hyphae). Each cell of *Spirogyra* filament contains one or more spiral bands of chloroplasts with numerous pyrenoids lying embedded in them, and one nucleus more or less centrally placed in the cell. In *Mucor* on the other hand each hypha is unseptate and coenocytic containing numerous nuclei. Chloroplasts are of course altogether absent, and instead of starch glycogen is deposited in the hyphae.

Reproduction. There is no regular vegetative reproduction in *Spirogyra* or *Mucor*. By casual breaking-down of the filament or the hypha vegetative reproduction may take place occasionally. The normal method of reproduction is, however, sexual in *Spirogyra* (asexual method being absent in it), and it is asexual in *Mucor* (sexual method being occasional in it under certain conditions).

(*a*) **Asexual Reproduction.** This is absent in *Spirogyra*, whereas in *Mucor* this is the commonest mode of reproduction. Thus in the latter numerous sporangia are formed, each at the end of an erect hypha. Each such sporangium contains a sterile dome-shaped columella and numerous minute spores. The spores are scattered by the wind and they germinate in suitable media.

(*b*) **Sexual Reproduction.** In both cases sexual reproduction takes place by the method of conjugation. In *Spirogyra* sexual reproduction which may be in the nature of scalariform conjugation or lateral conjugation, particularly the former, is [illegible] natural conditions; while in [illegible]

Mucor it grows into a sporangiophore which ends in a sporangium [illegible] spores but no columella. The spores are scattered by the wind and they germinate into *Mucor* mycelia in suitable media.

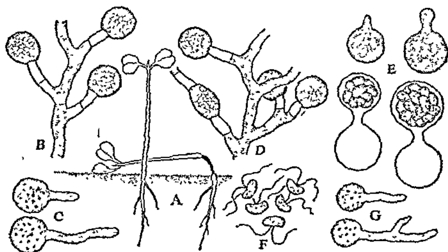
(*c*) **Parthenogenesis.** In both *Spirogyra* and *Mucor*, if conjugation fails, a gamete may be parthenogenetically converted into a thick-walled spore called azygospore.

2. *PYTHIUM* (40 sp.)

Pythium (fig. 589A) is a parasitic fungus, commonly attacking seedlings of cress and mustard at the base of their hypocotyl, under conditions of over-crowding and over-watering. It causes the disease commonly known as the 'damping off' of seedlings. Members of *Cruciferae* are particularly susceptible to this disease; other crops like tobacco, ginger, etc. are also infected by this fungus. The most common species of *Pythium* causing the 'damping off' is *P. de Baryanum*. When attacked, the seedlings become weakened at their base and soon fall over. At first the fungus is a parasite, but later after the death of the host seedlings it thrives on them as a saprophyte. The mycelium ramifies in all directions through the intercellular spaces, penetrating here and there into the living cells. At a later stage white cottony threads (hyphae) may be seen on the surface of the seedlings. The long, slender, much-branched hyphae are unseptate and coenocytic enclosing many small nuclei (cf. *Mucor* and *Vaucheria*).

Reproduction takes place both asexually and sexually.

Asexual Reproduction (fig. 589B-G). Here and there the mycelium sends out aerial hyphae through the stomata or the

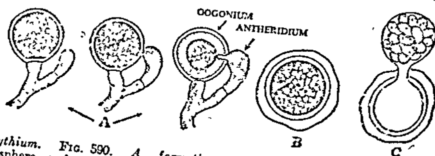


Pythium FIG. 589. *A*, healthy and infected seedlings; *B*, hyphae (conidiophores) with conidia; *C*, conidium germinates by sending out a germ-tube; *D*, hyphae with zoosporangia; *E*, zoosporangium germinating and finally forming a vesicle with zoospores; *F*, biciliated zoospores; and *G*, zoospore germinates by producing a germ-tube.

cuticle, which bear short lateral branches, each swelling into a spherical head. This head which is partitioned off at the base by a septum may act as a conidium or a zoosporangium

according to external conditions. (*a*) Under moist conditions it acts as a zoosporangium; it protrudes and bulges out into a bladder-like expansion (vesicle). The protoplasm migrates into it and divides to form a number of small naked uninucleate and biciliated zoospores. The zoospores, when set free, swim about in water for a short time. Soon they withdraw their cilia and clothe themselves with a wall. Eventually they infect a new seedling and germinate by putting forth a short hypha or *germ-tube* which branches freely within the tissue of the host. (*b*) Under dry conditions the head instead of forming zoospores behaves as a conidium (or conidiospore). It directly infects a new seedling and produces a germ-tube which branches freely within the tissue of the host.

Sexual Reproduction (fig. 590). After the death of the host the fungus leads a saprophytic life and takes to sexual repro-



Pythium. FIG. 590. *A*, formation of sexual organs—oogonium with oosphere, and antheridium (note the beak); *B*, thick-walled oospore inside oogonium formed after fertilization; and *C*, oospore germinates and produces a vesicle (zoosporangium) with zoospores.

duction possibly due to starvation. Within the dead tissues of the host or outside of it, the hyphal end swells into a spherical head due to migration of a large mass of protoplasm, forming the female organ, called **oogonium**. It is cut off from the supporting hypha by a partition wall. The oogonium may also be formed as an intercalary swelling of a hypha. The protoplasm of the oogonium soon becomes differentiated into two distinct regions—a central region with one big nucleus, constituting the female gamete or *oosphere*, and a peripheral region with many small nuclei, constituting the *periplasm*. From the same hypha or from another close to the oogonium a small branch arises. It swells and becomes more or less club-shaped, and is cut off by a septum at the base. This is the male organ, called **antheridium**. The protoplast of it becomes differentiated into a central male gamete which is uninucleate and an outer periplasm which is multinucleate. The nuclei of the periplasm soon degenerate. The antheridium bends

towards the oogonium and comes in contact with it. A short cylindrical tube, called the *fertilization-tube* or *beak*, is produced from it, which pierces the oogonium. The male gamete passes into the oogonium through this tube and fuses with the oosphere, and thus fertilization is effected. The fertilized oospore forms a thick wall round itself and rests for some months in the soil. Infection takes place in the way described above. The oospore germinates by putting forth a germ-tube or it forms a zoosporangium, the protoplasmic contents of which divide to form a number of zoospores.

3. *PHYTOPHTHORA* (13 sp.)

Occurrence. Common species of *Phytophthora* occurring in India are: *P. infestans* attacking potato plant, *P. palmivora* attacking coco-nut-palm and palmyra-palm, *P. arecae* attacking betel-nut-palm, *P. colocasiae* attacking taro (*Colocasia*), *P. parasitica* attacking castor plant, etc. *Phytophthora infestans* is a parasitic fungus which causes a serious disease in potato plants, known as 'late blight' (early blight being caused by *Alternaria solani*). The formation of black patches on the undersurface, less often on the upper, of the potato leaves indicates the diseased condition of the plant (fig. 591). The disease may spread to the entire leaf and other parts, and also

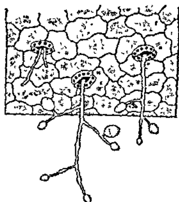
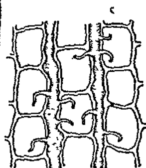




FIG. 591 FIG. 592 FIG. 593

Phytophthora. Fig. 591 A potato leaf showing the infected areas. Fig. 592 Sporangiophores protruding through the stomata and bearing sporangia Fig 593. Haustorial hyphae.

to the neighbouring plants if the weather is warm and humid The fungus causes 'wilting' of the leaves and 'rotting' of the tubers. It may also attack and destroy plants like tomato pepper, egg-plant, etc.

Structure. The mycelium is much branched, and the branches ramify through the intercellular spaces of the leaf, stem and tuber of the potato plant and send haustorial *hyphae* into the interior of the living, thin-walled cells to suck them (fig. 593). The haustorium may be hooked or sometimes spirally twisted, and simple or branched. The *mycelium* is non-septate and coenocytic.

Asexual Reproduction. The fungus commonly reproduces *asexually*. At the time of reproduction long erect branched hyphae, called sporangiophores, grow out of the *stomata* on the lower surface of the leaf (fig. 592). These bear ovoid sporangia at their apices. The sporangia are multinucleate, short-stalked and with an apiculate tip. The tip of the *sporangiophore* continues to grow pushing the sporangium to one side. Thus the sporangium, though terminal at first, appears to be lateral on the sporangiophore. When mature, the *sporangia* are dispersed by wind or washed away. The contents of a sporangium divide into several biciliate zoospores (fig. 594). The cilia are attached laterally on the zoospore. After escape from the sporangium the zoospores swim about; soon they lose their cilia and form a wall. They germinate by giving out

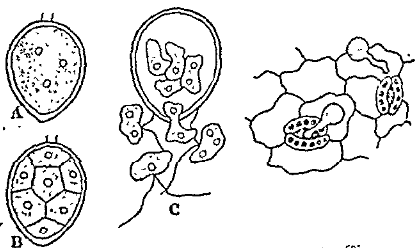


FIG. 594 FIG. 595

Phytophthora. Fig. 594. Asexual reproduction: *A*, a sporangium; *B*, a sporangium becoming a zoosporangium; and *C*, zoospores escaping. Fig. 595. Zoospores germinating on the host plant (note the infection through the stomata).

a *germ-tube* which passing through a stoma penetrates into the tissue of the leaf (fig. 595). Sometimes the sporangia

germinate directly, pushing out a germ-tube. The disease thus spreads rapidly from plant to plant. Sporangia and zoospores are short-lived, and the fungus hibernates in the potato tuber.

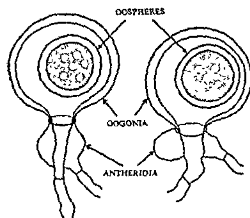


Fig. 596. Sexual reproduction in *Phytophthora*.

Sexual Reproduction. Sexual reproduction takes place by means of oogonia and antheridia (fig. 596). Oogonia are spherical or pear-shaped with smooth and reddish-brown wall; while the antheridia are broadly club-shaped. The antheridium develops before the oogonium and the latter, as it grows, penetrates into the former. The antheridium, as it swells, surrounds the stalk of the oogonium like a collar. Fertilization is generally amphigynous and it occurs in the following way: a nucleus passes out of the antheridium, penetrates into the base of the oogonium and ultimately fuses with the free egg-cell (oosphere) contained in the oogonium. After fertilization the oospore that is formed lies loosely in the oogonium. Germination of the oospore has not been observed yet. In many cases the antheridium is not formed. The oospore may then develop parthenogenetically.

Control of the Disease. 1. *Spraying*. The disease may be controlled by spraying the [illegible] e 6-8 inches [illegible] r hydroxide. [illegible] *Selection of* [illegible] should be avoided. [illegible] obtained from non-infected areas are the best in this respect. 3. *Low Temperature.* Storage of seed-potatoes at a low temperature, 40°F., is also practised.

4. *SACCHAROMYCES* (40 sp.)

Occurrence. Yeast (*Saccharomyces*) grows abundantly in organic substances rich in sugar such as the juice of date-palm, in the soil of the vineyard, and in grapes; it has the property of changing sugar into alcohol. This special power of yeast

has been taken advantage of in the manufacture of toddy, alcohol, wine, beer, etc. Yeast is also used in the making of

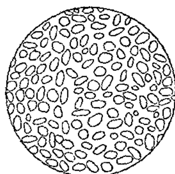


FIG. 597



FIG. 598

Yeast. Fig. 597. Yeast cells as seen under the microscope. Fig. 598. Budding or gemmation (see also fig. 388).

loaf, its sponginess being due to the production of CO_2 during fermentation. It is also used as a medicine because of its high vitamin content.

Structure (fig. 599). [Yeast was first microscopically examined by Leeuwenhoek in the year 1680. Its true nature was discovered by Schwann in Germany as late as 1836.] Its structure is very simple. A single cell represents the whole body of the plant. It is very minute in size and looks like a pin-head under the microscope. Each cell is oval or almost spherical, provided with a distinct cell-wall, possibly made of *chitin*, and contains a mass of cytoplasm with one or more vacuoles and a single nucleus. The nucleus contains a large vacuole, and this nuclear vacuole is a peculiarity in yeast. In the vacuole lies the nuclear reticulum with a nucleolus on one side. Embedded in the cytoplasm there are granules of glycogen, several oil-globules, and also protein compounds.

Reproduction. This takes place by two methods, viz. (1) vegetative and (2) asexual. Sexual reproduction takes place only in a few species.

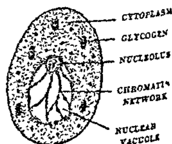


FIG. 599 One yeast cell magnified showing the nuclear vacuole

Vegetative Reproduction. (fig. 598). This takes place under normal conditions when the yeast cells grow in sugar solution. Each cell gives rise to one or more tiny outgrowths which gradually increase in size and are ultimately cut off from the mother cell; these then carry on a separate exist-

ence. The nucleus divides amitotically and one passes on to each outgrowth. This method of reproduction is known as vegetative **budding or gemmation** (*gemma*, a bud; pl. gemmae). The budding may be repeated resulting in the formation of one or more chains and even sub-chains of bead-like cells; these cells ultimately separate from one another into individual one-celled yeast plants.

Asexual Reproduction (fig. 600). Under unfavourable conditions, particularly when food supply is exhausted, the yeast

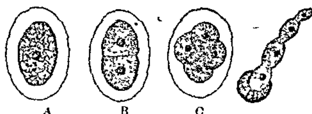


Fig. 600


Fig. 601

Yeast. Fig. 600. Formation of spores. Fig. 601. A spore germinating.

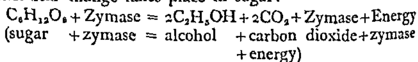
cell becomes larger and behaves as a sporangium, called **ascus.** When there is an abundance of oxygen the nucleus of the ascus divides into four. Protoplasm collects round each nucleus and thus four spores, called **ascospores,** are formed, each provided with a firm wall. Instead of four spores, sometimes two or eight may be formed. These are the resting spores, and can withstand unfavourable conditions of life. The wall of the ascus ruptures, and the spores are blown about by the wind. When they get a suitable medium they germinate and reproduce by the process of budding (fig. 601). In the light of recent research it may be said that this method is really parthenogenetic and not asexual.

Sexual Reproduction (fig. 602). Some species of yeast also reproduce sexually by conjugation. In the process of conjugation two adjacent cells send out short protuberances which unite with each other. The two nuclei then pass on to the conjugating tube and fuse with each other. The zygote (ascus) thus formed divides to produce eight nuclei. Each nucleus clothes itself with a wall, enlarges and becomes known as the ascospore. The ascospore germinates by budding or by dividing transversely. Sometimes the ascospores conjugate in pairs by short narrow conjugating tubes just before or after they have begun to germinate.



Yeast. Fig. 602. Conjugation of yeast cells and formation of ascospores.

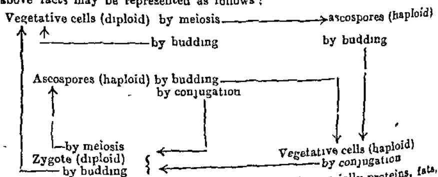
Alcoholic Fermentation. When the yeast cells grow in sugar solution, as in date-palm juice, palmyra-palm juice or grape juice, they set up fermentation (see p. 340) in it by means of an enzyme (zymase). Sugar is decomposed, and alcohol and carbon dioxide are the chief products formed. Carbon dioxide escapes, and often gives rise to frothing on the surface of the solution. When oxygen is abundantly supplied comparatively little alcohol is formed, but when the supply of oxygen is cut off alcohol is produced more freely. The following chemical change takes place in sugar:



$$C_6H_{12}O_6 + \text{Zymase} = 2C_2H_5OH + 2CO_2 + \text{Zymase} + \text{Energy}$$

(sugar + zymase = alcohol + carbon dioxide + zymase + energy)

Sexual Behaviour and Life-History. Sexuality in yeast is rather peculiar and unique with haploid and diploid stages without any system and regularity. Vegetative cells may be diploid or they may be haploid, while ascospores are of course always haploid. It has been observed that there may be sexual reproduction (conjugation) between two haploid vegetative cells or between two ascospores; it is not also uncommon to find conjugation taking place between a haploid vegetative cell and an ascospore. The result of conjugation in any case is a zygote which presumably is diploid. The zygote gives rise to a colony of diploid vegetative cells by *budding* or it gives rise to ascospores (usually 8 in number) *by meiosis*. The ascospores produce haploid vegetative cells *by budding* or they *conjugate* in pairs to form the zygote. The diploid cells in their turn multiply in number *by budding* or they form ascospores (usually 4 in number) *by meiosis*, which produce haploid vegetative cells *by budding*. The life-cycle based on the above facts may be represented as follows:



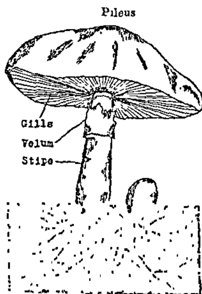
Yeast cells are very rich in digestible compounds, specially proteins, fats, carbohydrates, etc., and also enzymes and vitamins, and as such their value as food is considerable. These are purified, dried at about 125°C., and sold in the market as yeastvite.

5. *AGARICUS* (1,600 sp.)

Agaricus (=*Psalliota*), commonly called mushroom, is a fleshy saprophytic fungus. It grows on damp, rotten logs of wood, trunks of trees, decaying organic matter, and in damp soil rich in organic substance. The group to which *Agaricus* belongs includes various forms of mushrooms, puff-balls and toadstools.

Edible and Poisonous Forms. There are about 200 species of fleshy fungi that are edible; many more are non-edible, and about 12 species distinctly poisonous. All puff-balls are edible, particularly when they are young. Other common edible fungi are *Agaricus campestris* (= *Psalliota campestris*), *Morchella esculenta*, *Volvaria terastria*, *Lepiota mastoides*, etc. Certain species of *Amanita* which resemble edible *Agaricus* are extremely poisonous; these are, however, usually distinguished from the latter by their possession of a cup-like structure at the base, which is wanting in *Agaricus*. Edible types cannot be easily distinguished from poisonous ones except by critical examination. Generally speaking, (1) most of the species having a bright colour are to be regarded as poisonous; (2) those bearing pink spores and (3) those having a cup at the base are also poisonous; (4) a hot burning taste or acid flavour should, however, as a rule, be avoided (Watt); (5) those growing on the wood and (6) those whose stem does not break easily, when touched, are non-edible; and (7) non-edible types do not generally grow in open sunny places.

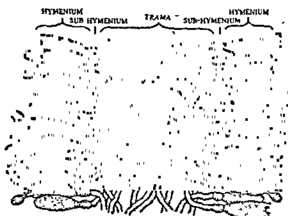
Structure (fig. 603). The mycelium consists of a much-branched mass of hyphae which unite (anastomose) at their points of contact and form a network in the substratum in which they grow. The hyphae are septate and hyaline, and contain finely granular protoplasm with vacuoles, many nuclei and conspicuous oil-globules. The aerial portion of the fungus constitutes its main body and is the '**fructification**' or fruit-body of the plant. It consists of a fleshy stalk and an umbrella-like head borne on its top. The stalk and the head are composed of an interwoven mass of hyphae, and in sections they have the appearance of a tissue—a false tissue, known as pseudo-parenchyma. The stalk of the fungus is known as the **stipe** (a stem), and the expanded head or cap on its top is known as the **pileus** (a cap or hat). The pileus is more or less rounded and convex. When young, the fructification is spherical in shape (button stage) and is completely enclosed by a thin membranous covering, called the **velum.** With the growth of the fructification, specially the pileus, the velum is ruptured, the remnants of which remain surrounding the stipe as a ring (annulus). Ultimately the pileus spreads in an umbrella-like fashion on the top of the stipe. From the undersurface of the pileus suspend a very large number of thin vertical plate-like structures, extending from the



Agaricus. Fig. 603. Two plants, young and old, with ramifying mycelia.

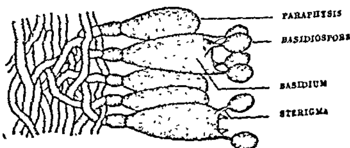
stipe to the margin of the pileus; these are known as the **gills** or **lamellae.** They vary in number from 300 to 600 for each fructification. Each gill bears innumerable spores on both the surfaces.

Reproduction (figs. 604-6). This takes place by asexual method only. The spores are known in this case as the **basidiospores,** and are borne by the gills on both surfaces. A gill in



Agaricus. Fig. 604. A gill in section.

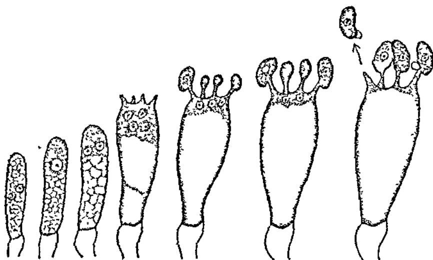
section shows three distinct portions: trama, sub-hymenium and hymenium. **Trama** is the central portion of the gill and consists of an interwoven mass (false tissue) of long slender hyphae. The hyphal cells of the trama curve outwards on either side of the gill and terminate in a layer of small



Agaricus. Fig. 605. A portion of the gill in section.

rounded cells; this layer is the **sub-hymenium.** External to it lies the hymenium composed of a layer of club-shaped cells, called **basidia.** Some of them bear spores; while others, the so-called **paraphyses,** are in reality immature basidia. Each basidium bears four basidiospores—in some cases two only—on short slender stalks, known as **sterigmata** (sing. *sterigma*).

The basidiospores, when mature, fall off and germinate under favourable conditions.



Agaricus. FIG. 606. Stages in the development of basidium and basidiospore. (For explanation see text)

Development of Basidium and Basidiospore (fig. 606). The basidium is at first binucleate The two nuclei, each with n chromosomes, fuse to form the zygote nucleus. The latter, evidently provided with $2n$ chromosomes, undergoes reduction division giving n chromosomes. Slender projection in number—are formed at the end at the end, and a nucleus migrates end-cell with a nucleus in it is the hilum, is formed at the junction of drop of water accumulates on the h. with the drop of water suddenly shoots off from the sterigma. This explosive mechanism is not, however, understood.

CHAPTER V

LICHENS (15,000 sp.)

General Description. Lichens comprising 400 genera form a large peculiar and interesting group of plants, being associations of certain algae and fungi, the latter constituting the greater part of the lichen body. The associations of different algae and fungi *give rise to distinct species*. *Lichens* commonly occur as greyish-green or bright-coloured incrustations, 1 to several inches in diameter, on tree trunks, wooden posts, logs of wood, rocks, walls and ground, or sometimes hanging in shaggy tufts, a few to several inches in length, from branches of trees. They have a variety of colours: white, greyish-green, yellow, orange, brown, red or black. Many of them grow under extreme conditions of humidity and temperature

and may survive long periods of desiccation. They are very widely distributed in all regions. In lichens algae and fungi live together in intimate relationship. The two organisms are of mutual help to each other and lead a symbiotic life. The fungi absorb water and mineral matter and supply the

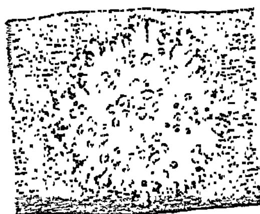


Fig. 607

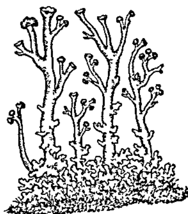


Fig. 608

Lichens. Fig. 607. A foliose lichen (*Parmelia*). Fig. 608. A fruticose lichen (*Cladonia*).

same to the algae, while the latter in their turn prepare food and supply it to the fungi. Lichens are thus very good examples of symbiosis. If they are separated from their associations they lead a precarious life, more particularly the fungi.

Classification. Lichens may be classified into three principal groups: (*a*) **crustose lichens**, forming hard granular crusts closely adhering to rocks, tree trunks and certain soils, e.g. *Graphis* and *Lecanora*; they show very little differentiation between the upper surface and the lower; (*b*) **foliose lichens** (fig. 607), forming definite flattened leaf-like thalli with lobed margin adhering to walls, tree trunks, rocks and ground by delicate rhizoids (**rhizines**), e.g. *Parmelia* and *Physcia*; they show distinct differentiation between the upper surface and the lower; and (*c*) **fruticose lichens**, forming much-branched shrub-like body which remains attached by the narrow basal portion only; the branches may be flat and ribbon-like or these may be slender and filamentous; such lichens may be standing erect, e.g. *Cladonia* (fig. 608), or drooping from branches, e.g. old man's beard (*Usnea*; fig. 609).

Thallus. The main framework of the thallus is made up of an interwoven mass of hyphae of a fungus, commonly an ascomycete (ascolichen) or in a few cases a basidiomycete (basi-

diolichen), enclosing a unicellular or filamentous type of blue-



Fig. 609

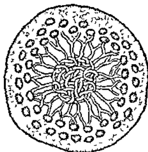


Fig. 610



Fig. 611

Fig 609. A fruticose lichen (*Usnea*). Fig. 610. A section through the thallus of *Usnea*. Fig. 611. A soredium.

green or green alga. The types of the alga and the fungus associated in a lichen are always constant. In some lichens the algae remain scattered in the thallus and in others these occur in 1 or 2 layers. A section through the thallus (fig. 612) of a foliose lichen shows a loose mass of hyphae in the central region—the so-called medulla and a compact mass in the peripheral region—the so-called cortex. Between these two regions usually lies the algal layer (commonly called the gonidial layer) with numerous algal cells (commonly called gonidia) held together in the meshes of the hyphae. In *Usnea*, a fruticose lichen, the thallus (fig. 610) seems to be differentiated into a central compact core

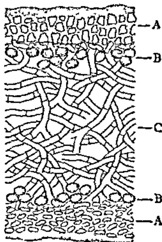


Fig. 612. A section through the thallus of a foliose lichen *A*, cortex; *B*, gonidial layer; and *C*, medulla.

of hyphae, a region of loosely interwoven hyphae, an alg region and externally another compact region.

Reproduction. Lichens reproduce themselves in a varie of ways: (*a*) vegetative, (*b*) asexual and (*c*) sexual.

(*a*) *Vegetative.* Vegetative reproduction takes place by ti granular bodies known as **soredia**. Each soredium (fig. 611) is little mass of alga of one or more cells wrapped up in a weft fungal hyphae. Soredia are sometimes produced in larg numbers on the thallus like a coating of dust particles, as i *Usnea* and *Cladonia*; these are then blown about by wind

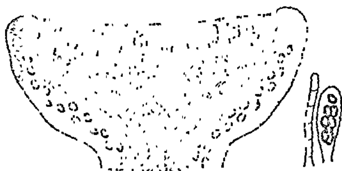


FIG. 613 FIG. 614

FIG. 613. A section through an apothecium; note the asci and the paraphyses. FIG. 614. An ascus and a paraphysis.

These germinate directly into new lichen thalli or form new soredia. Sometimes the thallus becomes separated into frag ments. Each such fragment is seen to grow up to the size of the parent thallus. In *Usnea* the branches may be broken up by the wind into several fragments. Some of them at least get stuck up to some branches of trees and grow up. Some lichens may form outgrowths (isidia) with both algal cells and fungal hyphae on the surface of the thallus. These outgrowths may be detached from the parent thallus and then they develop into new thalli.

(*b*) *Asexual.* Reproductive organs, asexual or sexual, are always formed by the fungus of the lichen body. Asexual reproduction commonly takes place by ascospores in asco lichens, and the fruiting body or fructification is known as the **ascogonium or ascocarp.** In *Usnea* and many other ascolichens the ascocarp takes the shape of an open cup or saucer, very much like that of *Peziza*, known as the **apothecium.** Each apothecium (fig. 613) consists of an interwoven mass of hyphae with a surface layer of slender erect elongated cells, known as the hymenium. The hymenium consists of a series of club shaped cells—the asci—intermixed with a large number of

sterile hyphae—the **paraphyses.** In each ascus usually eight **ascospores** develop but the number varies from 1 to 8 (fig. 614). Ascospores are liberated and those coming in contact with the right type of alga produce the lichen thallus. In some lichens, however, the ascogonium is a closed chamber, known as the **perithecium,** with an apical opening. The asci and the paraphyses develop in a layer on the inner wall of the perithecium. Basidiolichens reproduce by basidiospores, as in *Agaricus.* The ascogonium in some cases at least is supposed to be formed after fertilization, as described below. Besides, most lichens reproduce by conidia-like bodies known as **pycnospores** which are formed by a process of abstriction from the terminal cells of certain hyphae. The pycnospores develop in special receptacles or chambers known as *pycnidia* which externally appear as small black dots on the surface of the thallus, or as small protuberances on the margin of the thallus-lobe.

(c) *Sexual.* Sexual organs have been observed in a very few cases only, as in *Collema.* Male cells, called **spermatia,**[1] develop within a chamber known as the **spermagonium.** A number of spermagonia may be formed on the thallus. The inner wall of the spermagonium is lined with a layer of short slender branches—the sterigmata. Spermatia are formed from these branches by abstriction like conidia. They are very minute in size and cylindrical in form. The spermatia after they are liberated float in moisture on the thallus. The female organ is a multicellular filament known as the **archicarp.** It consists of a spirally coiled basal portion lying embedded in the thallus, known as the **carpogonium,** and an extended portion lying beyond the thallus, known as the **trichogyne.** The spermatia come in contact with the sticky protruding tip of the trichogyne, and its protoplast migrates into the trichogyne. After nuclear fusion the carpogonium enlarges and becomes converted into the ascogonium (apothecium). Ascogenous hyphae develop from the base of the carpogonium after fertilization, and these produce asci at their ends. The vegetative hyphae of the thallus simultaneously grow and form the investing tissue of the ascogonium.

Uses. Lichens growing on rocks disintegrate them forming soils, thus preparing the ground first for mosses and subsequently for higher plants. Lichens have a variety of uses.

[1] The nature of spermatia is a disputed point. Although in some cases spermatia act as male cells, in others they have been found to act as spores (pycnospores) germinating independently.

Some of them are a valuable source of food to wild animals, as reindeer moss (*Cladonia*) of the arctic tundra. In some countries lichens are fried for cattle food and to some extent also for human food. Some types are used as medicines. Some yield dyes. Litmus is prepared from certain lichens. Some species are used in cosmetics and in perfumes.

CHAPTER VI

BRYOPHYTA

Classification of Bryophyta (22,700 sp.)

I. Hepaticae or liverworts (8,500 sp.), e.g. *Riccia* and *Marchantia* (commonly called thallose or thalloid liverworts) and *Anthoceros* (commonly called horned liverwort).

II. Musci or mosses (14,200 sp.), e.g. *Funaria* and *Polytrichum* (commonly called true mosses).

1. *RICCIA* (135 sp.)

Riccia (fig. 615) is a thalloid liverwort showing distinct dichotomous branching and taking on a rosette form. It belongs to the family *Ricciaceae*. The thallus is a flattened structure showing a dorsal (upper) surface with a longitudinal groove along the whole length of the mid-rib, and a ventral (lower) surface with usually a row of scales at the apex and a number of unicellular hairy structures known as **rhizoids**. The thallus is thicker in the middle and thinner at the two margins. The growth of the thallus takes place by a single wedge-shaped apical cell. The segments of the thallus are obcordate or linear with their margin sometimes ciliated. The plant grows as a green carpet on wet ground, old damp walls, old tree trunks and moist rocks; rarely it is aquatic, e.g. *Riccia fluitans*. A cross-section of the thallus (fig. 616) shows the following structure: (*a*) a discontinuous upper epidermis, (*b*) an assimilatory tissue consisting of rows of cells with chloroplasts, leaving narrow irregular air-spaces between the rows for facility of exchange of gases, (*c*) a lower colourless tissue consisting of fairly big thin-walled cells for storage of water and food, and (*d*) a lower epidermis with many hair-like rhizoids which are of two kinds—smooth and tuberculate.

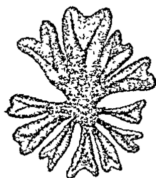


FIG. 615. A *Riccia* plant.

Reproduction. *Riccia* plant is the gametophyte, i.e. it reproduces sexually by gametes. The two kinds of gametes—male and female—are borne in special structures known as the antheridia and the archegonia respectively. Some species are *monoecious* and others *dioecious*. In the monoecious species antheridia and archegonia develop together in the median groove on the dorsal (upper) side of the thallus. They grow in acropetal succession from the base of the thallus to its apex. Each **antheridium** (fig. 617) which is more or less pear-shaped develops in a deep chamber formed by the overgrowth of the surrounding tissue of the thallus, and consists of a short stalk, a sterile wall and a compact mass of antherozoid mother-cells. Each mother-cell by a single division forms two cells, each of which grows into a small twisted biciliated male gamete or **antherozoid** (fig. 618). Each **archegonium** (figs. 619-20) *also lies sun*ken in a similar chamber. It is a short-stalked, flask-shaped

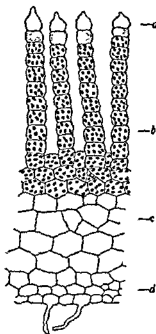


FIG. 616. *Riccia* thallus (see text, p. 446).

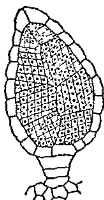
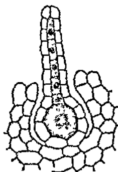
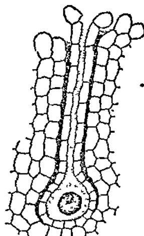

FIG. 617


FIG. 618


FIG. 619


FIG. 620

Riccia. Fig. 617. An antheridium. Fig. 618. An antherozoid. Fig. 619 A young archegonium. Fig. 620. A mature archegonium.

body with a swollen basal portion known as the **venter** and a narrow tubular upper portion known as the **neck** which

occasionally projects beyond the epidermis and turns purplish. The neck contains a few neck canal-cells (usually four) surrounded by six vertical rows of jacket cells, and the venter contains a ventral canal-cell and an **ovum** (female gamete). All the cells except the ovum degenerate into mucilage. **Fertilization** takes place in the usual way. The antherozoids swim to the archegonium. The mucilage swells and forces out the cover cells of the neck canal (fig. 620). As the mucilage dissolves an open passage is established through the neck. The antherozoids enter the archegonium and one of them fuses with the ovum. After fertilization the ovum clothes itself with a wall and becomes the **oospore.**

Development of Sporophyte. The fertilized egg, i.e. the oospore, gives rise to the **sporophyte.** The sporophyte is a simple spherical body called the **capsule** (fig. 621). It consists of a spore-sac and a wall surrounding it, the latter made of a

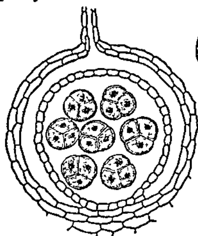


Fig. 621





Fig. 622

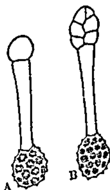


Fig. 623

Riccia. Fig. 621. Sporophyte (capsule) within enlarged archegonium. Fig. 622. Spores; *A*, spores in a tetrad; *B*, a single spore. Fig. 623 *A-B*, early stages in the germination of spore.

single layer. The capsule develops *in situ* within the venter of the archegonium. With the growth of the capsule the venter also grows and invests the latter. This investing structure is called the **calyptra.** The spore-sac contains a loose mass of spore mother-cells. Each mother-cell undergoes reduction division and forms a *tetrad of spores* (fig. 622A). Eventually by the rupture of the calyptra and the wall of the capsule the spores are set free. Each spore (fig. 622B) is provided with a coat of two layers (three layers according to some authors). The outer layer is cutinized and the inner one made of pectose and callose. The whole coat is irregularly

thickened and folded. In the germination of the spore the outer layer bursts and the inner one grows into a germ-tube which gradually develops into *Riccia* thallus (fig. 623). The sporophyte develops within the gametophyte and is wholly dependent upon the latter for its nutrition.

Alteration of Generations. *The plant passes through two* successive generations—gametophyte and sporophyte—to complete its life-history. The gametophyte begins with the spore and ends in the formation of the gametes—antherozoid and ovum—prior to fertilization; while the sporophyte begins with the oospore and ends in the spore mother-cells. The gametophyte gives rise to the sporophyte through sexual reproduction, and the sporophyte to the gametophyte through asexual reproduction. Thus there is a regular alternation of generations in *Riccia.*

2. *MARCHANTIA* (65 sp.)

Marchantia (figs. 624-5) is a rosette type of thalloid liverwort showing conspicuous dichotomous branching, dorsiventral symmetry and a distinct mid-rib. It belongs to the family *Marchantiaceae*, of which *M. palmata* is a common and widespread species. *Marchantia* grows on damp ground or old walls and spreads rapidly during the rainy season

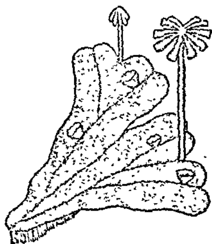


FIG. 624

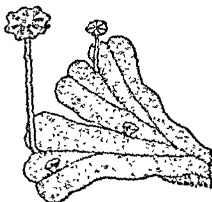


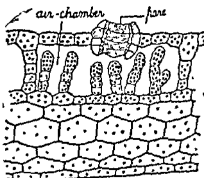
FIG. 625

Marchantia. Fig. 624. Female plant with archegoniphores and gemma-cups. Fig. 625. Male plant with antheridiophores and gemma-cups.

forming a sort of green carpet. It occurs abundantly in the cold climate of the hills. The thallus bears on its under-surface (ventral) a number of unicellular rhizoids of two kinds

—tuberculate and smooth-walled, a row of scales along the mid-rib, and 2 or 3 rows of them on each side of the mid-rib (the outer row being near the margin of the thallus). On the upper surface (dorsal) it bears a number of cup-like outgrowths, known as the **gemma-cups**, on the mid-rib. The thalli of some plants bear special *male* reproductive branches known as the **antheridiophores** (fig. 625) and those of other plants bear special *female* reproductive branches known as the **archegoniophores** (fig. 624). The two can be easily recognized—the former having a flat circular brownish lobed disc on the top, and the latter having a green smooth disc projected into distinct rays, at first bending downwards and later becoming horizontal. The growing point of the thallus lies in the notch of dichotomy and is represented by one or a few cells.

A section through the thallus (fig. 626) shows: (1) a single-layered **upper epidermis** which is interspersed with numerous air-pores; the cells of the epidermis contain chloroplasts; (2) **air-chambers** lying below the epidermis and communicating with the exterior through a centrally placed air-pore; externally the chambers often appear as polygonal areas on the thallus; each air-pore is surrounded by a few tiers of cells; from the floor of the air-chamber arise short chains of cells, branched or unbranched, each cell containing several chloroplasts; these chains of green cells constitute the **assimilatory tissue**; (3) **storage tissue** consisting of several layers of large thin-walled parenchymatous cells which are mostly devoid of chloroplasts except a few upper layers; the cells mostly contain starch grains but there are some mucilage- and oil-containing cells here and there; and (4) a single-layered **lower epidermis** without chloroplasts but it bears numerous rhizoids and some scales.



Marchantia. FIG. 626. Section through the thallus.

Reproduction. Vegetative reproduction may take place (*a*) by the decay of the old basal portion of the thallus, thus separating a branch, (*b*) by the formation of adventitious branches which get detached from the thallus, or (*c*) by gemmae (fig. 628) which develop in the gemma-cup or cupule (fig. 627). Each gemma is a small, more or less circular, flattened structure with a conspicuous depression on each side. The growing point lies in

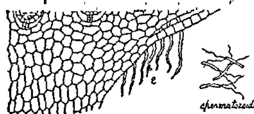

FIG. 627


FIG. 628

Marchantia. FIG. 627. A gemma-cup. FIG. 628. A gemma.

the depression. When the gemma gets detached from the gemma-cup it grows out into a dichotomously branched thallus. It is green in colour containing chloroplasts.

Sexual Reproduction. The thallus is the **gametophyte**, i.e. it reproduces sexually by gametes. *Marchantia* is **dioecious**, i.e. male and female plants are distinct and separate. The male plants bear antheridia or male reproductive organs on special erect branches called antheridiophores (fig. 625), and the female plants bear archegonia or female reproductive organs on almost similar branches called archegoniophores (fig. 624). The **antheridiophore** (fig. 629) consists of an erect cylindrical **stalk** and a more or less circular, commonly 8-lobed disc or **receptacle** on the top. The stalk has two longitudinal channels on one side from which rhizoids and scales develop. The receptacle bears on its lower side a number of rhizoids and scales, and on the upper several small air-chambers and rows of antheridia. Each air-chamber communicates with the exterior through a minute air-pore and has within it chains of green cells, as in the thallus. The antheridia are produced in acropetal order (the oldest towards the centre and the youngest towards the margin) from the segments of 8 growing points which are located at the tips of lobes. Each **antheridium** (fig. 629) develops in a cavity lying embedded in the receptacle, and is more or less ovoid in shape; it communicates with the exterior by a narrow canal known as the **ostiole**. The antheridium is composed of a mass of small cubical cells (antherozoid mother-cells) surrounded by a single-layered wall. Each antherozoid mother-cell develops a minute biciliated spindle-shaped male gamete known as the **antherozoid**. The **archegoniophore** (figs. 630-1) similarly consists of a **stalk** (often longer than that of the antheridiophore) and an 8-lobed star-shaped disc or receptacle with mostly 9 radiating rays or arms, somewhat like the ribs of an umbrella. The rays alternate with the lobes of the disc. The growing point is located at the tip of the lobe of



Marchantia. FIG. 629. Section through the antheridiophore. *a*, antheridium; *b*, air-pore; *c*, ostiole; *d*, air-chamber; *e* hairs, *f*, scales. Some spermatozoids on the right.

the disc between two rays. Evidently there are 8 such growing points. A group of archegonia develop from the segments of each growing point in acropetal order, at first on the upper side. There are altogether 8 groups of archegonia alternating with the rays. By rapid elongation of the cells of the upper side of the disc the growing points are, however, pushed down-

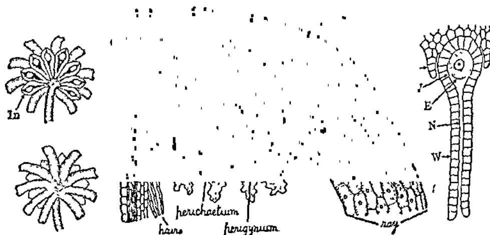


FIG. 630 FIG. 631 FIG. 632

Marchantia. Fig. 630. (*Top*) undersurface of the archegoniophore; *In*, involucre; (*bottom*) upper surface of the same. Fig. 631. Section through the archegoniophore showing air-chambers with chains of green cells and air-pores, ray, archegonia and stalk. Fig. 632. An archegonium; P, perigynium or pseudo-perianth; V, venter; E, egg-cell; N, neck; and W, wall.

wards and inwards with the result that the groups of archegonia come to lie underneath the disc. Each growing point and the youngest archegonium are brought close to the stalk, while the oldest archegonium lies near the margin. The stalk of the receptacle has two longitudinal channels on one side with rhizoids and scales, as in the male stalk. On the upper side the receptacle is provided with a number of air-chambers, as in the male receptacle, while groups of archegonia develop on the lower side hanging downwards. A membranous curtain-like outgrowth, known as the *involucre* (or perichaetium), fringed at the edges, is formed surrounding a group of archegonia as a protective covering (figs. 630-1). Besides, at the base of each archegonium, ultimately surrounding it after fertilization, there is a cup-shaped outgrowth of it, known as the pseudo-perianth or perigynium (figs. 631-2). The archegonium (fig. 632) is a flask-shaped body consisting of a swollen basal portion—the venter, a narrow elongated portion—the neck, and a very short stout multicellular stalk. The neck of the archegonium, when young, is covered by a lid made of a few

'cap' or 'cover' cells. The venter contains a large egg-cell or ovum (female gamete) and a small ventral canal-cell, while the neck contains a row of usually 4-8 neck canal-cells. The wall of the archegonium is made of six vertical rows of jacket cells. **Fertilization** takes place in the following way. When the antheridium bursts the antherozoids swim out of the antheridial chamber through the ostiole and frisk about in water lashing with their cilia. As the archegonium matures the neck canal-cells and the ventral canal-cell dissolve and are converted into mucilage; the latter swells up in contact with moisture, and the lid is forced open. A clear passage is thus formed. The mucilage contains some protein matter which attracts the antherozoids. These swim to the archegonium through the medium of dews or rain water and many of them enter into the venter through the neck Finally one of them fuses with the ovum in the venter. Fertilization is thus effected. After fertilization the ovum develops a wall round itself and becomes the **oospore.**

Development and Structure of Sporogonium (figs. 633-4). The oospore germinates *in situ* and gives rise to the **sporo-**

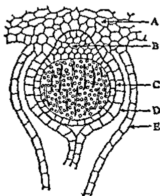


FIG. 633

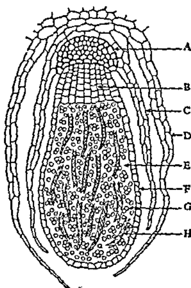


FIG. 634



FIG. 635

Marchantia. Fig 633. A young sporogonium; *A*, tissue of the gametophyte; *B*, foot; *C*, capsule (wall); *D*, archegonium (wall); and *E*, perigynium or pseudo-perianth. Fig 634. A mature sporogonium; *A*, foot; *B*, seta; *C*, remnant of venter (calyptra); *D*, perigynium or pseudo-perianth; *E*, capsule; *F*, wall of the capsule; *G*, spore; and *H*, elater. Fig. 635. An elater (enlarged).

gonium. The sporogonium is the **sporophyte**, i.e. it reproduces asexually by spores. The oospore divides into an upper cell and a lower. The lower cell further divides and produces a **foot** and a short stalk called **seta** which elongates later. The foot penetrates into the tissue of the receptacle and absorbs nutritive materials from it. The upper cell divides and forms the **capsule**. The capsule consists of a single layer of wall-cells and a mass of small cells (**archesporium**) inside it. Some of the archesporial cells grow up into elongated, spindle-shaped structures with internal spiral thickenings; these are known as the **elaters** (figs. 634-5). Other cells of the archesporium form **spore mother-cells**. Each spore mother-cell divides by the process of meiosis *to* form *four spores* in a tetrad. After fertilization other parts of the archegoniophore also grow. Thus the wall of the venter grows and forms the **calyptra** which surrounds the capsule (fig. 634C); the neck withers and disappears. The **perigynium** (figs. 633E and 634D) grows rapidly and ultimately surrounds the sporogonium. The sporophyte is thus adequately protected by the calyptra, perigynium and involucre. As the seta elongates, it pushes the capsule through the calyptra; a remnant of the calyptra may be seen around the capsule (fig. 634C). As the capsule matures, the seta further elongates and pushes the former beyond the perigynium and the involucre. Finally the capsule dehisces, rather irregularly, from the apex to about the middle of it into a number of segments, and the spores are discharged (fig. 636). Under humid condition the elaters undergo a twisting movement and push the spores out of the capsule. The spore germinates and gives rise to a short tube which develops into the *Marchantia* thallus.

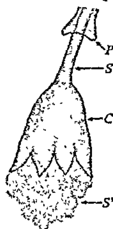


FIG. 636

Marchantia. FIG. 636. Sporogonium dehiscing and discharging spores; *P*, perigynium; *S*, seta; *C*, capsule; and *S'*, spores.

Alternation of Generations (fig. 637). *Marchantia* shows two stages or generations in its life-history. The plant itself is the gametophyte having *haploid* chromosomes, and the sporogonium the sporophyte having *diploid* chromosomes. The gametophyte reproduces sexually by gametes and gives rise to the sporophyte, and the sporophyte reproduces asexually by spores and gives rise to the gametophyte. Thus the two generations regularly alternate with each other. All the

stages from the oospore to the spore mother-cells represent the sporophytic or asexual generation, and all the stages from the spores to the gametes—the ovum and the spermatozoid—represent the gametophytic or sexual generation.

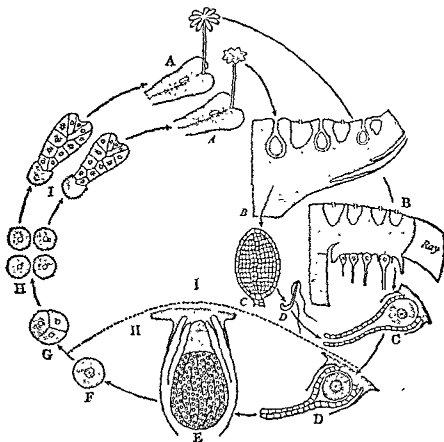


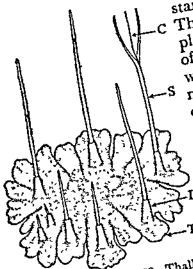
FIG. 637. Life-cycle of *Marchantia*. I, gametophytic generation (haploid or *n*) and II, sporophytic generation (diploid or 2*n*). *A*, male thallus with antheridiophore; *B*, antheridiophore with antheridia (in section); *C*, an antheridium; *D*, an antherozoid; A, female thallus with archegoniophore; B, archegoniophore with archegonia (in section); C, an archegonium with egg-cell; D, zygote within archegonium; E, sporogonium; F, spore mother-cell; G, spore-tetrad; H, spores, and I, young sporophytes (male and female).

3. *ANTHOCEROS* (60 sp.)

Anthoceros (fig. 638), commonly called horned liverwort, is a very interesting plant inasmuch as it shows certain special features in its life-history, particularly helping one to understand the course of evolution in the higher plants. While the plant shows a simple and primitive type of gametophyte, its sporophyte has already reached a high degree of development and complexity. The systematic position of *Anthoceros* is, therefore, uncertain. For the present it is treated as belonging to a separate order (Anthocerotales)

of Hepaticae. The features of interest are mostly connected with the sporophyte, and these are as follows: (a) semi-independent nature of the sporophyte with the development of a considerable amount of green tissue and stomata showing thereby a tendency towards an independent life; (b) its massive foot for greater absorption of water and mineral salts from the gametophyte; further with the decay of the gametophytic tissue the foot may touch the ground and absorb water and mineral salts directly from the soil—another step towards an independent career; (c) complexity of the sporophyte with a considerable development of sterile tissue in it being an early indication of a more complex and quite independent sporophyte at a later stage in the evolution of higher plants; (d) establishment of the sterile axis (columella) representing the beginning of a conducting system, and (e) method of shedding spores comparable to that of ferns and allied plants.

Gametophyte. *Anthoceros* (fig. 638) is a cosmopolitan plant and grows abundantly both in the hills and the plains on damp soils, hill sides, rotten tree trunks, damp walls, etc. The plant body of *Anthoceros* is a very simple type of gametophytic thallus, usually ¾-1½ inches in diameter, with the reproductive organs (male and female or either of the two according as the species is monoecious or dioecious) sunken in it, and at a later stage showing cylindrical deep-green sporophytes standing erect on the thallus. The thallus is a small dark-green plate-like dorsiventral structure, often very irregularly lobed and without mid-rib. While there are many smooth-walled rhizoids developing on the ventral (lower) surface, scales are altogether absent. There are some intercellular mucilage-filled cavities at the ventral (lower) side of the thallus, occupied by colonies of *Nostoc*. The internal structure of the thallus is very simple consisting of a mass of thin-walled parenchyma without any differentiation of tissues. Each cell commonly contains a single large chloroplast with a large pyrenoid in it—a character not found in other Bryophyta. The pyrenoid consists of a mass of minute disc- or spindle-shaped bodies which are the rudiments of starch grains.



Anthoceros. Fig. 638 Thallus of *Anthoceros* with sporophytes; *C*, columella; *S*, sporophyte (capsule); *I*, involucre; and *T*, thallus (gametophytic).

Reproduction. Vegetative reproduction may take place by the continued growth of the thallus and the separation of it into segments. In dry regions tubers may be formed on the

margin, which may grow into new thalli under favourable conditions. **Sexual reproduction.** *Anthoceros* thallus is the gametophyte and it reproduces sexually by gametes. Species of *Anthoceros* may be monoecious (homothallic) bearing both antheridia and archegonia or dioecious (heterothallic) bearing either of the two. The sexual organs lie embedded in the dorsal (upper) surface of the thallus, antheridia appearing first in the monoecious species. **Antheridia** (fig. 639) grow in small groups (usually 2-4) within closed chambers, called antheridial chambers, which are filled with mucilage. Each chamber is covered over by a sort of roof made of 1 or 2 layers of cells. Each antheridium consists of a short multicellular stalk, a sterile outer layer (one or more cells thick) and a compact mass of antherozoid mother-cells. Each mother-cell gives rise to a single minute biciliated antherozoid. **Archegonia** (fig. 640) develop singly and separately lying

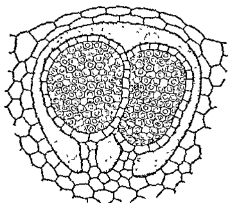


FIG. 639.

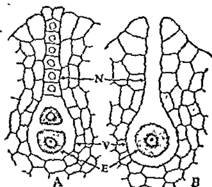


FIG. 640

chamber (each
Fig. 640. Two
ll, ventral canal-
h egg-cell ready
gg-cell.

partially embedded in the thallus. When fully developed each archegonium consists of a venter and a neck. The neck consists of a vertical row of 4-6 neck canal-cells, and the venter of a ventral canal-cell and an egg-cell. At maturity the neck canal-cells and the ventral canal-cell get disorganized and become converted into mucilage. While the major part of the archegonium remains sunken in the thallus the upper end of the neck only protrudes out of it. When young the neck of the archegonium is covered by four 'cover' cells which sepa-

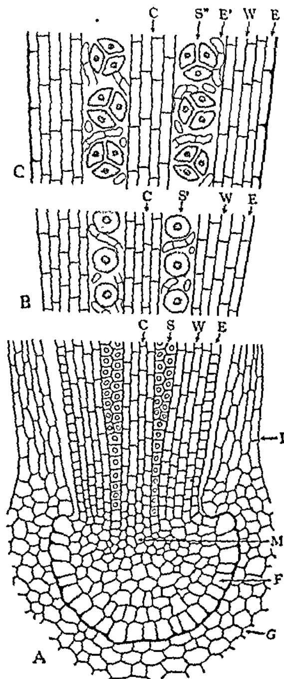


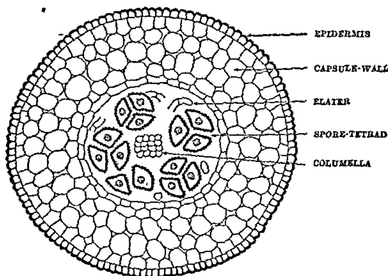
Fig. 641

Anthoceros. Fig. 641. Longitudinal section of sporophyte (in three segments)—A, basal; B, middle; and C, higher (next upper portion is represented by fig. 642); C, columella; S, sporogenous tissue; S', spore mother-cells; S", spore-tetrads; E', elaters; W, wall of the capsule; E, epidermis; I, involucre or sheath; M, meristematic tissue; F, foot; and G, gametophytic tissue.

rate out later. Fertilization is effected in the following way. By the breakdown of the roof of the antheridial chamber an outlet is formed for the antherozoids to escape. They swim to the archegonium and enter through its neck. Finally one antherozoid fuses with the egg-cell in the venter. After fertilization a zygote (oospore) is formed, which being diploid (*with 2n chromosomes*) represents the beginning of the sporophytic generation.

Sporophyte. The sporophyte develops from the zygote and consists of a foot and a capsule. It is surrounded at the base by a sheath or involucre formed by an upward growth of the archegonium for a time. Soon after fertilization the zygote grows and completely fills up the venter. It clothes itself with a wall and divides at first vertically into two cells; the second division which is transverse cuts them off into four cells; and the third division at

right angles to the first one cuts them off into two tiers of four cells each. The lower tier by further divisions finally gives rise to a massive sterile structure at the base, thus increasing the absorbing surface; this is the **foot** which looks more or less like an inverted cap (fig. 641A). The upper tier finally gives rise to the **capsule.** The capsule (fig. 638) is a slender cylindrical deep-green structure, usually $\frac{3}{4}$-$1\frac{1}{2}$ inches long, sometimes longer in some species. A longitudinal section through it shows the following regions (fig. 641). (a) A **meristematic tissue** at the base of the capsule, by the activity of which the sporophyte continues to elongate and the sporocytes, i.e. the spore mother-cells, also continue to be formed. (b) Centrally a sterile tissue—the **columella,** consisting of four rows of elongated cells each way, showing in a transection of the capsule a solid square block of 16 rows of cells; the sterile columella is an early indication of differentiation of the conducting system at a later stage in the higher plants. (c) Surrounding the columella there is a cylinder of **sporogenous tissue**



Anthoceros. FIG. 642. Transection of a sporophyte through the mature (upper) portion.

(or archesporium). (d) Surrounding this there is the **capsule-wall** which is a jacket of green sterile tissue, 4-8 layers of cells thick, with 2 or sometimes more chloroplasts in each cell; the outermost layer of this is the epidermis which is strongly thickened and cutinized, and provided with stomata. Because of the presence of the chloroplasts the sporophyte can manu-

facture most of its food and is only dependent on the gametophyte for water and mineral salts. The sporophyte is, therefore, a semi-independent body. The sporogenous tissue may extend down to the base of the capsule or only half-way down, and may be 1, 2, 3 or 4 layers of cells in thickness. The sporophyte matures from the apex downwards, i.e. the base is younger than the apex. The sporogenous cells develop into small groups of sterile cells called **elaters** and small groups of **spores** in an alternating manner. The elaters are mostly smooth-walled and rarely with spiral bands. Each spore mother-cell undergoes reduction division and four spores are formed in a tetrad (fig. 642). The sporophyte reproduces asexually by these spores. With the formation of the spores the gametophytic generation begins. The mature capsule dehisces from the apex downwards into two horn-like valves with the slender columella standing free in the centre (fig. 638) and the spores are thrown out. The spore germinates and gives rise to an *Anthoceros* thallus.

Alternation of Generations. The life-history of *Anthoceros* is complete in two generations—gametophytic and sporophytic, which regularly alternate with each other. The *Anthoceros* thallus is the main gametophytic body with *haploid* or *n* chromosomes, and the capsule with the foot represents the sporophyte with *diploid* or *2n* chromosomes. The gametophyte reproduces sexually by gametes and gives rise to the sporophyte, and the latter reproduces asexually by spores and gives rise to the gametophyte. Thus the two generations regularly alternate with each other, one producing the other.

4. A MOSS

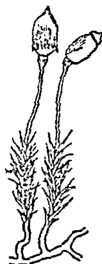
[Life-history may be studied by referring to *Funaria* or *Polytrichum*.]

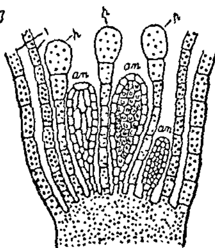
Moss (fig. 643) occurs most commonly on old damp walls, trunks of trees, and on damp ground during the rainy season, while in winter it is seen to dry up. It is gregarious in habit; wherever it grows it forms a green patch or a soft velvet-like green carpet. There are about 14,200 species of mosses and allies.

Moss plant is small, about an inch or so in height, and consists of a short axis with spirally arranged minute green leaves which are crowded towards the apex; true roots are absent; it bears a number of slender multicellular branching

rhizoids which perform the functions of roots. The axis may be branched or unbranched.

Life-cycle. The life-cycle of moss, as described below, is complete in two stages—gametophytic and sporophytic. The moss plant itself is the gametophyte and this is followed by another structure, called sporogonium, which grows dependent on the moss plant and is the sporophyte (fig. 648).





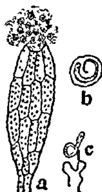


FIG. 643 FIG. 644 FIG. 645

Moss. Fig. 643. Two moss plants. Fig. 644. Apex of a male shoot; *an*, antheridium; *l*, leaves; *p*, paraphysis. Fig. 645. *a*, antheridium (burst); *b*, antherozoid mother-cell; *c*, biciliated antherozoid.

Gametophyte. The moss plant is the **gametophyte**, i.e. it bears gametes and reproduces by the sexual method. For this purpose highly defferentiated male and female organs are developed at the apex of the shoot. The male organ is known as the **antheridium** and the female organ as the **archegonium.** These organs are sometimes intermixed with some *multicellular* hair-like structures known as the **paraphyses** (*para*, beside ; *phyo*, to grow or an offshoot). Antheridia and archegonia may occur together on the same branch or shoot or on two branches of the same plant (monoecious) or on two separate plants (dioecious).

The **antheridium** (figs. 644-5) is a multicellular, short-stalked, club-shaped body which is filled up with numerous small cells, known as the antherozoid mother-cells. The antheridium bursts at the apex and the mother-cells are liberated through it in a mass of mucilage. The mucilaginous walls of mother-cells get dissolved in water and the **antherozoids** or spermatozoids (fig. 645C) or male gametes are set free. They

are very minute in size, spirally coiled and biciliated; after liberation they swim in water that collects at the apex of the moss plant after rains.

The **archegonium** (figs. 646-7) is also a multicellular body, but it is flask-shaped in appearance. It is provided with a short multicellular stalk and consists of two portions: the lower swollen portion is known as the **venter** (belly), and the upper tube-like portion as the **neck**. The neck is long narrow

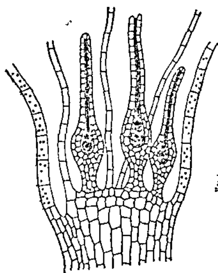


Fig. 646

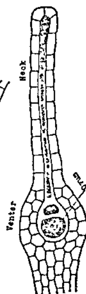
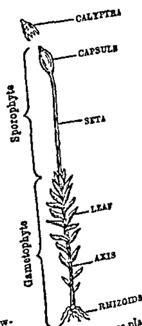


Fig. 647



Moss. Fig. 646. Apex of a female shoot showing three archegonia, three paraphyses and two leaves. Fig. 647. An archegonium.

Fig. 648 A moss plant.

and straight. Within the venter there lies a large cell which is the **ovum** (egg-cell or oosphere) or female gamete; above this lies a small ventral canal-cell, and higher up in the neck there are a few neck canal-cells. Except the ovum other cells mentioned above are functionless and soon get disorganized. The neck at first remains closed at the apex by a sort of lid, but as the archegonium matures the lid opens and allows the antherozoids to enter and pass through it.

Fertilization is effected in the following way. When the archegonium matures it secretes mucilage with cane-sugar. This attracts a swarm of antherozoids which enter through the neck canal and pass down into the venter; one of them fuses with the ovum and the rest die out. After fertilization the zygote clothes itself with a wall and is then known as the **oospore.** The latter germinates *in situ* and gives rise to the sporogonium on the moss plant (fig. 648).

Sporophyte. The sporogonium is the sporophyte, i.e. it bears spores and reproduces by the asexual method. The sporogonium consists of **foot, seta** and **capsule.** The seta is the slender stalk which bears the capsule. The foot is the small conical structure which buries itself in the tissue of the moss plant. The sporogonium is not an independent plant; it grows as a semi-parasite on the moss plant. It partly draws its food from the moss plant (gametophyte) and partly it manufactures its own food. The oospore divides into two cells—the upper and the lower; the lower cell by repeated divisions forms the seta with the foot, and the upper cell forms the

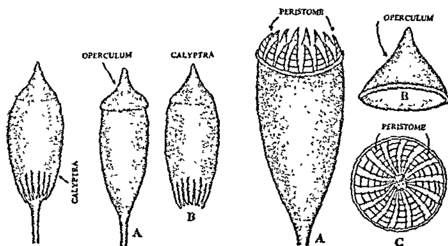


Fig. 649. Fig. 650. Fig. 651.

Moss Capsule. Fig. 649. A capsule covered by calyptra. Fig. 650. *A*, a capsule without calyptra; *B*, detached calyptra. Fig. 651. *A*, a capsule showing peristome—open; *B*, operculum; *C*, peristome—closed (surface view).

multicellular complex body of the capsule. As the oospore grows the archegonium gets ruptured somewhere in the middle. The upper half of the ruptured archegonium then forms a sort of cap covering the apex of the capsule, and is known as the **calyptra**. The calyptra occurs as a loose cap, and is afterwards blown away (figs. 649-50).

The capsule (fig. 652) is a complex body, and more or less pear-shaped in appearance. A longitudinal section through it shows the following regions.

1. **Operculum.** It is the lid of the capsule, and lies on the top of it. It is a few layers in thickness. When the capsule

dehisces the operculum comes away as a circular, cup-shaped lid.

2. **Annulus.** It is a special ring-like layer of epidermal cells, lying around the capsule at the base of the operculum. It is by the rupture of the annulus that the capsule dehisces.

3. **Peristome.** When the operculum falls off, the top of the capsule is seen to be furnished with one or two rows of thickened, tooth-like projections, constituting the peristome. These teeth are hygroscopic, and when they are dry they open out and help dispersion of spores (fig. 651).

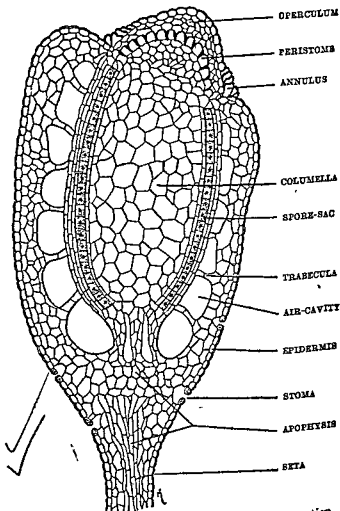


Fig. 652. Capsule of moss in longitudinal section.

4. **Columella.** This is the solid central column of the

capsule. It is sterile, i.e. it contains no spores. Water and food material accumulate here for the developing spores.

5. **Spore-sac.** It lies around the columella and contains numerous small cells. It is bounded externally by a few layers of cells, and internally by one layer. Each cell of the spore-sac is a spore mother-cell. It soon undergoes reduction division to form four spores. The capsule dehisces at the annulus with the lid falling off. The capsule, being seated on a long stalk, is disturbed by wind, and the spores are thrown out of the spore-sac.

6. **Air-cavity.** It lies as a cylindrical cavity surrounding the spore-sac, and is traversed by delicate strands of cells, known as the **trabeculae** (sing. trabecula).

7. ***Capsule Wall.*** *It is composed of* (*a*) a few layers of chloroplast-bearing cells just outside the air-cavity, (*b*) a few layers of bigger cells containing water—the sub-epidermis, and (*c*) externally a distinct layer—the epidermis.

8. **Apophysis.** It is the solid basal portion of the capsule with (*a*) a distinct epidermis bearing a few stomata, (*b*) a sub-epidermis containing chloroplasts, and (*c*) a central region of elongated cells containing water—the water conducting tissue.

Germination of the Spore. After dehiscence of the capsule the spores are scattered by the wind, and they germinate under favourable conditions. The spore grows out into a short tube which *lengthens and ultimately forms* a green, much-branched filament; this is known as the **protonema** (*fig.* 653). *It produces here and* there long slender and brown rhizoids, and a number of small lateral buds. These lateral buds develop into new moss plants which form a colony again. Thus the life-cycle of moss is completed.


FIG. 653. Protonema of moss (note the buds and rhizoids).

Alternation of Generations (figs. 654-5). Moss plant shows two generations which regularly alternate with each other, and the life-history is only complete when the plant passes through these two generations. The moss plant itself is the gameto-

phyte (or gamete-bearing plant), and the sporogonium is the sporophyte (or spore-bearing plant). Through sexual reproduction by gametes (antherozoid and ovum) the gametophyte gives rise to the sporophyte, and through asexual reproduction by spores the sporophyte gives rise to the gametophyte. In the life-history of moss the reduction of chromosomes to half or *n* number takes place for the first time in the formation of

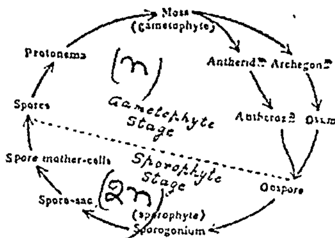


FIG. 651. Life cycle of moss (diagrammatic) showing alternation of generations gametophyte stage (haploid or *n*) and sporophyte stage (diploid or 2*n*).

spores from the spore mother-cell. The spore is, therefore, the beginning of the sexual or gametophytic generation, and the various stages from the spore to the antherozoid and ovum represent the gametophytic or sexual generation because in all of them the chromosome number is *n*. The antherozoid and the ovum fuse, and the chromosome number is doubled, i.e. 2*n* is restored in the oospore. The oospore, therefore, represents the beginning of the asexual or sporophytic generation, and the oospore, sporogonium and spore mother-cells represent the sporophytic or asexual generation because in all of them the chromosome number is 2*n*.

Vegetative Reproduction. The gametophytic plant reproduces vegetatively in a variety of ways: (1) by the formation of multicellular 'gemmae' which develop in groups usually at the apex of the leaf or at the apex of a comparatively long branch; they get detached and germinate in a moist soil, putting out a protonema; (2) by protonema which develops from any part of the plant—*stem, leaf or even rhizoid*; (3) by the production of resting buds on the protonema; they get detached from the protonema and develop into new moss plants; and (4) by separation of protonemal branches.

Some of the cells of the sporogonium may also develop protonema which by budding gives rise to moss plants. This is a case of **apospory** (see p. 370).

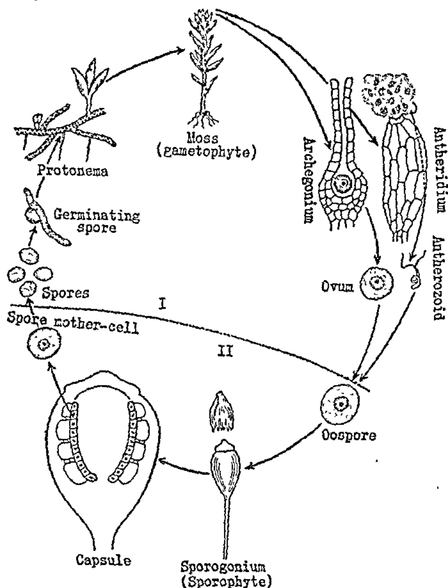


FIG. 655. Life-cycle of moss. *I*, gametophytic generation (haploid or *n*) and *II*, sporophytic generation (diploid or 2*n*).

CHAPTER VII

PTERIDOPHYTA

Classification of Pteridophyta (10,000 sp.)

I. Filicinae or ferns (7,800 sp.), e.g. *Dryopteris*, *Nephrolepis*, *Pteris*, *Adiantum*, etc.

II. Equisetinae or horsetails (25 sp.), e g. *Equisetum*.

III. Lycopodinae or club-mosses (940 sp.), e g. *Lycopodium* and *Selaginella*.

1. A FERN

[Life-history may be studied by referring to *Dryopteris* (= *Aspidium*), *Nephrolepis* or *Pteris*]

Ferns (fig. 656) are a group of highly developed cryptogams and are widely distributed all over the world. They grow abundantly in cool shady moist places, both in the hills and in



Fig. 656. A fern plant; *left*, portion of a pinna with sori.

the plains. The stem is mostly a rhizome, but sometimes it is erect and aerial, as in tree ferns. Roots are adventitious (fibrous) growing usually in clusters from the rhizome. Leaves

are usually pinnately compound, circinate when young (fig. 656), and are characterized by great apical growth. The lateral leaflets borne by the axis or rachis are known as the pinnae (sing. pinna); sometimes these are again more or less deeply pinnately lobed, and then each lobe is known as the pinnule. The stem and the petiole are covered with numerous brownish scales, known as the ramenta.

Internal Structure of the Fern Stem (or Petiole). (1) **Epidermis**—a single layer of cells with the outer walls thickened and cutinized. (2) **Sclerenchyma**—a few layers of sclerenchyma occur below the epidermis. (3) **Ground tissue** is made up of a continuous mass of polygonal parenchymatous cells. (4) **Endodermis**—a single layer of narrow cells surrounding each stele; this layer is often much thickened, particularly on the inner side. (5) **Steles**—in the young stem or petiole the stele is more or less horseshoe-shaped, but in the *older* part the stele is broken up usually into two or three smaller steles. Each stele consists of (*a*) **pericycle**, (*b*) **phloem** and (*c*) **xylem**. Pericycle surrounds the stele as a single layer (sometimes a double layer, particularly at the sides) and contains starch grains. Phloem surrounds the central xylem, bundle being concentric, and consists of sieve tubes and phloem parenchyma. Xylem lies in the centre surrounded by phloem. It consists usually of two groups of protoxylem at the two ends, and metaxylem in the middle. Protoxylem is made of spiral tracheids and metaxylem of scalariform tracheids.

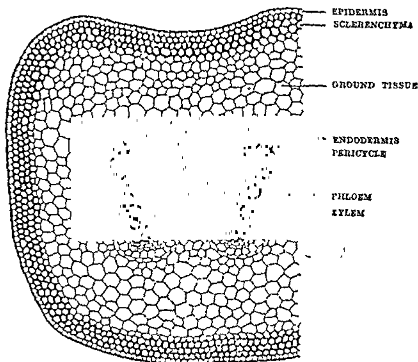


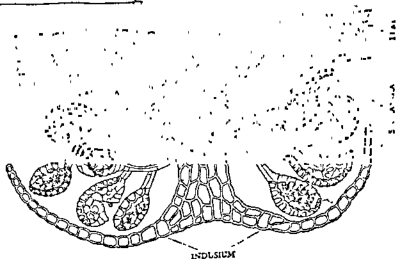
FIG. 657. Fern petiole in transection.

Life-cycle. The life-cycle of fern, as described below, is complete in two stages—sporophytic and gametophytic. The

fern plant is the sporophyte and this is followed by another structure, called prothallus, which grows in the soil independent of the fern plant and is the gametophyte (fig. 660).

Sporophyte. The fern plant (fig. 656), as stated above, is the sporophyte, i.e. it bears spores and reproduces by the asexual method.

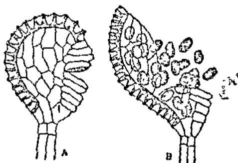
Sporangia and Spores. On the under-surface of the ordinary vegetative leaf or specially modified foliage leaf, i.e. the **sporophyll** (as the spore-bearing leaf is called), a number of dark brown structures, pale green when young, may be seen; these are called **sori** (sing. sorus). They develop on the veins, and are arranged in two rows in each leaflet or pinna of the leaf. Each sorus (fig. 658) consists of a large number of short-stalked **sporangia** (sing. sporangium) which are covered over by a reniform or kidney-shaped shield, called the **indusium.** The sporangia and the indusium develop from a papilla-like outgrowth of the leaf; this outgrowth is called the **placenta.**



Fern. Fig. 658. Section through a sorus.

Each **sporangium** (fig. 659) consists of a short multicellular **stalk and a capsule** which is biconvex. Inside the capsule lies a mass of very small grains; these are the spores. At first there are 16 spore mother-cells in the capsule; these undergo reduction division into 32 daughter-cells. The daughter-cells then divide mitotically and 64 spores are formed. The wall of the capsule consists of a single layer of thin-walled cells, with a specially thickened and cutinized band or ring running round the margin of the capsule. This ring which is incomplete and thin-walled on one side is called the annulus, and

the unthickened portion of it is known as the **stomium.** When the spores mature they increase in size, and under dry conditions the capsule bursts at the stomium, liberating the spores. When the capsule bursts, the annulus bends back exposing the spores, and then suddenly it returns to its original position, ejecting the spores by this process. The fern plant is *homosporous*, i.e. it bears only one kind of spores.



Fern FIG 659. Sporangia (capsule and stalk); A, capsule just open at *the stomium*; *B, capsule has burst* with the annulus bending back

Gametophyte. The prothallus (fig 660) is the gametophyte, i.e. it bears gametes and reproduces by the sexual method. Under favourable conditions of temperature and moisture the spore germinates. At first it gives rise to a short green filament resembling an alga or moss protonema. Subsequently by further division of cells it produces a small green flat heart-shaped body, about one-third of an inch across, this is known

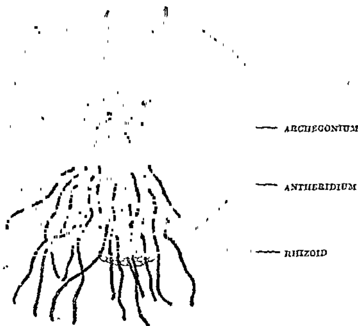


FIG. 660. Prothallus of fern.

as the **prothallus.** At maturity the prothallus is a thin flat mass of tissue, its margin consisting of a single layer of cells, while

the central p
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prothallus ; th
and mineral
tures are produced on the under-surface of the prothallus; these are antheridia or male organs, and archegonia or female organs. The former develop amongst the rhizoids and the latter near the groove.

The antheridium (fig. 661) is a spherical or oval body con- ... cells. In each ... ntherozoid (or ... ty of nuclear material. It bears a number of fine threads, called cilia, near its tip.

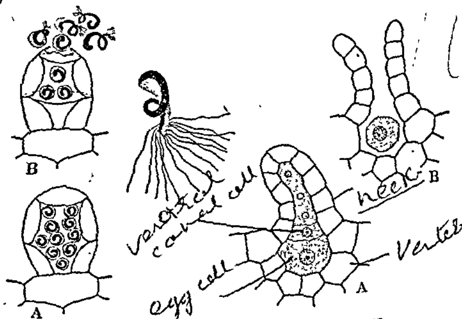


Fig. 661. Fig. 662.

Fern. Fig. 661. Antheridium. *A*, a young one with antherozoid mother-cells; *B*, a mature one after bursting; and *C*, an antherozoid. *Fig. 662.* Archegonium. *A*, a young one; and *B*, a mature one ready for fertilization. Note the venter and the neck.

The archegonium (fig. 662) is a flask-shaped body. The swollen basal portion of it is known as the *venter*, and the slender tube-like upper portion as *the neck*. Inside the venter there lies a single large cell; this is the ovum (or egg-cell or oosphere) or female gamete; and above this lies the ventral canal-cell. The neck consists of a longitudinal canal with a

few neck canal-cells in a row, and a wall made of a few cells arranged in four rows. The neck is short and curved, and the venter lies embedded, partially or completely, in the prothallus.

Fertilization. When the antheridium matures it bursts and the antherozoids are liberated. They swim about in water by means of their cilia. As the archegonium matures it secretes mucilage and malic acid.

They quickly vibrate around the ovum with which one of them soon fuses. After this fusion (fertilization) the rest of the antherozoids die

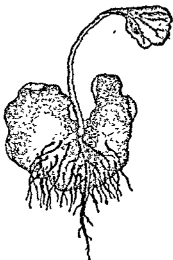


Fig. 663. Prothallus of fern with young sporophyte.

phyte (with a green leaf and a root) still attached to the prothallus (fig. 663). With the penetration of the root into the soil and decay of the prothallus the young sporophyte develops into a fern plant as an independent body.

Alternation of Generations (figs. 664-5). Fern plant, as the life-history shows, passes through two stages or generations. The plant itself is the sporophyte, and the prothallus the gametophyte. The sporophyte or the fern plant reproduces asexually by spores and gives rise to the gametophyte or the prothallus, and the latter reproduces sexually by gametes (antherozoid and ovum) and gives rise to the sporophyte or the fern plant. Thus the two generations regularly alternate with each other. In the life-history of fern $2n$ chromosomes are met with for the first time in the oospore and, therefore, this is the beginning of the sporophytic generation, and all the stages from the oospore to the spore mother-cells represent the sporophytic or asexual generation of fern. Reduction of chromosomes to n number takes place in the formation of spores from the spore mother-cells and, therefore, they (spores) represent the beginning of the gametophytic generation, and all the stages from the spores to the gametes (antherozoid and

ovum) constitute the gametophytic or sexual generation. It is noticeable that the sporophyte (fern plant) has already reached a high degree of development and complexity, and with the formation of roots and green leaves with chloroplasts, has

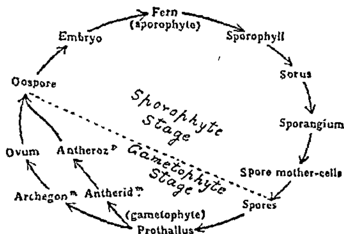


FIG. 664. Life-cycle of fern (diagrammatic) showing alternation of generations; sporophyte stage (diploid or $2n$) and gametophyte stage (haploid or n).

become independent of the gametophyte. As a matter of fact the sporophyte of fern is the all-important body, while the gametophyte of it is very insignificant.

COMPARATIVE STUDY OF MOSS AND FERN

Habit and Habitat. Moss plants are small, usually ½-1 *inch* in height, growing in clusters from protonemal buds forming a *green soft cushion* on damp ground or damp old walls; while fern plants are much bigger in *size*, usually a few inches to a few feet in height, growing close together in cool shady moist places.

Structure. The structure of the moss plant is simple *consisting* of a short axis with spirally arranged minute leaves and a *number* of *rhizoids* at the base of the axis; while the *fern plant* is *much* more *complicated* in *structure consisting* of a rhizome with scales or ramenta, several adventitious roots and usually large well-developed leaves, often *pinnately divided*. The internal structure of moss is also *simple with rudimentary conducting* tissue in the *form* of *a small group* of elongated colourless cells; while that of fern is much more complicated consisting of definite vascular system (xylem and phloem) and other differentiated tissues

Vegetative Reproduction. Moss sometimes *reproduces vegetatively* by splitting of protonemal branches *or by resting* buds on the *protonema* or by *gemmae on* the leaf and the branch; while fern reproduces by its *rhizome* and in some cases by leaf-tips, as in walking *ferns* (see *fig. 506*).

Alternation of Generations. Both moss and fern are higher *cryptogams* showing a regular alternation of *generations* in *their* life-history. Moss plant is the gametophyte which is the dominant phase in its life-cycle, while the sporogonium is the sporophyte which is dependent on the gametophyte as a semi-parasite. The *order* is reversed in the case *of fern*. The fern plant is the sporophyte which is the dominant phase in its life cycle, while

the prothallus is the gametophyte which although an independent body is very much reduced in size and is inconspicuous. Thus from moss to fern

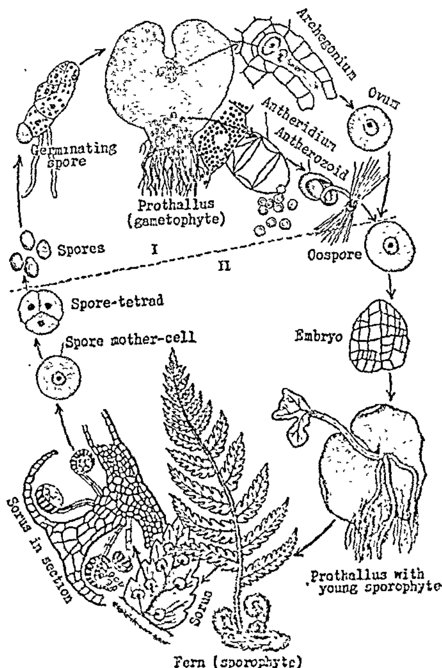


Fig. 665. Life cycle of fern. I, gametophytic generation (haploid or n) and II, sporophytic generation (diploid or 2n).

a reduction of gametophyte and an advance of sporophyte are evident. In both the cases the sporophyte reproduces asexually by spores and gives rise to the gametophyte and the latter reproduces sexually by gametes and gives

rise to the sporophyte, and thus the two generations regularly *alternate with each other.*

Gametophyte and Sexual Reproduction. Moss plant itself is the gametophyte and it bears antheridia and archegonia at the apices of its shoots for the purpose of sexual reproduction (see figs. 644 and 646); whereas in fern the prothallus is the gametophyte which bears similar sexual organs—antheridia and archegonia (see figs. 660-1). The antheridia of moss are usually elongated and club-shaped, while those of fern usually spherical. Antherozoids of moss are biciliated, while those of fern multiciliated. The mode of fertilization is practically the same in both the cases but in moss the archegonia secrete cane-sugar to attract the antherozoids, while in fern malic acid is secreted for this purpose. In both moss and fern the antherozoids swim to the archegonia through the medium of water. After fertilization the oospore in either case grows and gives rise to the sporophyte, i.e. the sporogonium of moss or the fern plant, as the case may be.

Sporophyte and Asexual Reproduction. In moss the sporogonium is the *sporophyte*; it is a small slender elongated body growing on the moss plant as a semi-parasite, and consists of a foot, seta and capsule. The capsule is a somewhat complicated structure showing differentiation of parts (see fig. 652). In fern the main plant body is the sporophyte. Here ordinary leaves behave as sporophylls. Each sporophyll bears on its under-surface a number of sori which are only collections of sporangia. The capsule of fern (see figs. 658-9) is much simpler than that of moss. The moss capsule bursts at the annulus with the operculum coming out as a lid, and the ejection of spores is helped by the movement of the peristome; while in fern the capsule bursts at the stomium, and the ejection of spores is helped by the movement of the annulus. In each case the spore on germination gives rise to the gametophyte, i.e. the moss plant or the prothallus of fern, as the case may be. In the case of moss, however, the spore produces the protonema first and the moss plants develop from it as lateral buds.

2. *EQUISETUM* (25 sp.)

The family *Equisetaceae* is represented by a single genus. *Equisetum* (fig. 668), commonly called horsetail, comprises about 25 species which are widely distributed, specially in the cool and temperate regions of the world. They are usually abundant in marshy places or by the side of a spring or stream of water in the hills. *Equisetum* consists of a long slender horizontal underground rhizome, giving rise at intervals to erect aerial shoots, often not exceeding a metre in height. *Equisetum debile*, common in Assam, however, grows to a height of about 10-12 feet. The rhizome often develops short tuber-like b
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some species, however, branched shoots are fertile. Leaves are minute and scaly, and form a whorl at each node. These

leaves are free and pointed at their tips but united below to form a sheath round the base of the internode. The lateral branches develop alternating with these leaves and grow upwards piercing the sheath. In consequence of reduction of leaf-laminae, the branches become green and carry on photosynthesis. Roots are slender, adventitious and much branched developing from each node of the rhizome.

Internal Structure of the Stem (figs. 666-7). It has distinct nodes and internodes, with longitudinal ridges and furrows. The internal structure is as follows:

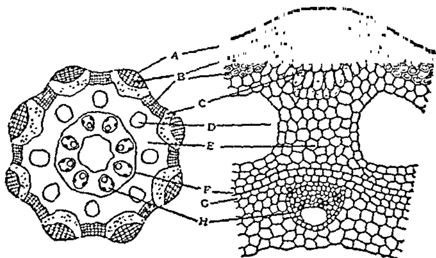


FIG. 666 FIG. 667

Equisetum. Fig. 666. Section of stem (diagrammatic). Fig. 667. A portion of the section (magnified). *A*, epidermis; *B*, hypodermis (sclerenchyma); *C*, outer cortex with chloroplasts (note the stomata), *D*, air-cavities; *E*, general cortex; *F*, endodermis; *G*, pericycle; *H*, vascular bundles (see text; note the pith and the pith cavity.

(1) **Epidermis**—a single outer layer of cells with a deposit of silica in their outer walls. It is wavy in outline and has stomata in two rows in the furrow. (2) **Sclerenchyma**—sclerenchyma develops, specially in the ridges, below the epidermis, interrupted in the furrows by the underlying cortex. (3) **Cortex**—it is many-layered, and in the middle of it large air-canals, each corresponding to a groove, are formed. Outer layers of the cortex contain chloroplasts; leaves being scaly, carbon-assimilation is carried on by the cortex of the stem. The assimilating tissue extends up to the epidermis in the furrow where the stomata lie. (4) **Endodermis**—cortex is demarcated from the stele by a definite layer of endodermis. (5) **Pericycle**—the layer lying internal to the endodermis is the pericycle. (6) **Vascular bundles**—these are closed, collateral, and arranged in a ring. Each vascular bundle is very feebly developed with xylem on the inner side and a small patch of phloem on the outer; xylem consists of some scalariform tracheids; there is an air passage in it. (7) **Pith cavity**—there is a big air-cavity corresponding to the pith.

rise to the sporophyte, and thus the two generations regularly alternate with each other.

Gametophyte and Sexual Reproduction. Moss plant itself is the gametophyte and it bears antheridia and archegonia at the apices of its shoots for the purpose of sexual reproduction (see figs. 644 and 646); whereas in fern the prothallus is the gametophyte which bears similar sexual organs—antheridia and archegonia (see figs. 660-1). The antheridia of moss are usually elongated and club-shaped, while those of fern usually spherical. Antherozoids of moss are biciliated, while those of fern multiciliated. The mode of fertilization is practically the same in both the cases but in moss the archegonia secrete cane-sugar to attract the antherozoids, while in fern malic acid is secreted for this purpose. In both moss and fern the antherozoids swim to the archegonia through the medium of water. After fertilization the oospore in either case grows and gives rise to the sporophyte, i.e the sporogonium of moss or the fern plant, as the case may be.

Sporophyte and Asexual Reproduction. In moss the sporogonium is the sporophyte; it is a small slender elongated body growing on the moss plant as a semi-parasite, and consists of a foot, seta and capsule. The capsule is a somewhat complicated structure showing differentiation of parts (see fig. 652). In fern the main plant body is the sporophyte. Here ordinary leaves behave as sporophylls. Each sporophyll bears on its under-surface a number of sori which are only collections of sporangia. The capsule of fern (see figs. 658-9) is much simpler than that of moss. The moss capsule bursts at the annulus with the operculum coming out as a lid, and the ejection of spores is helped by the movement of the peristome; while in fern the capsule bursts at the stomium, and the ejection of spores is helped by the movement of the annulus. In each case the spore on germination gives rise to the gametophyte, i.e. the moss plant or the prothallus of fern, as the case may be. In the case of moss, however, the spore produces the protonema first and the moss plants develop from it as lateral buds.

2. *EQUISETUM* (25 sp.)

The family *Equisetaceae* is represented by a single genus. *Equisetum* (fig. 668), commonly called horsetail, comprises about 25 species which are widely distributed, specially in the cool and temperate regions of the world. They are usually abundant in marshy places or by the side of a spring or stream of water in the hills. *Equisetum* consists of a long slender horizontal underground rhizome, giving rise at intervals to erect aerial shoots, often not exceeding a metre in height. *Equisetum debile*, common in Assam, however, grows to a height of about 10-12 feet. The rhizome often develops short tuber-like bodies which serve as reservoirs of food materials. The outline of the stem is wavy with ridges and furrows which alternate at the next node. Each aerial shoot is simple or branched. [illegible] vegetative in function [illegible] nd short-lived; after [illegible] up. In some species, however, branched shoots are fertile. Leaves are minute and scaly, and form a whorl at each node. These

leaves are free and pointed at their tips but united below to form a sheath round the base of the internode. The lateral branches develop alternating with these leaves and grow upwards piercing the sheath. In consequence of reduction of leaf-laminae, the branches become green and carry on photosynthesis. Roots are slender, adventitious and much branched developing from each node of the rhizome.

Internal Structure of the Stem (figs. 666-7). It has distinct nodes and internodes, with longitudinal ridges and furrows. The internal structure is as follows:

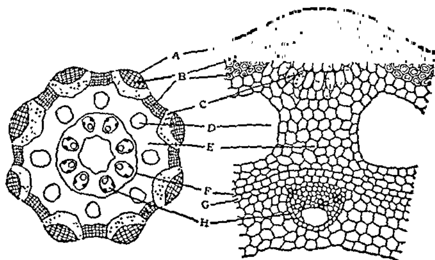


FIG. 666 FIG. 667

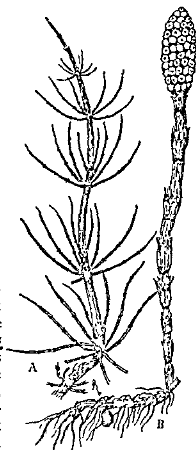
Equisetum. Fig. 666. Section of stem (diagrammatic). Fig. 667. A portion of the section (magnified). A, epidermis; *B*, hypodermis (sclerenchyma); *C*, outer cortex with chloroplasts (note the stomata); *D*, air-cavities; *E*, general cortex; *F*, endodermis; *G*, pericycle; *H*, vascular bundles (see text; note the pith and the pith cavity.

(1) **Epidermis**—a single outer layer of cells with a deposit of silica in their outer walls. It is wavy in outline and has stomata in two rows in the furrow. (2) **Sclerenchyma**—sclerenchyma develops, specially in the ridges, below the epidermis, interrupted in the furrows by the underlying cortex. (3) ***Cortex***—*it is many-layered, and in the middle of it large air-canals*, each corresponding to a groove, are formed. Outer layers of the cortex contain chloroplasts; leaves being scaly, carbon-assimilation is carried on by the cortex of the stem. The assimilating tissue extends up to the epidermis in the furrow where the stomata lie. (4) **Endodermis**—cortex is demarcated *from the stele by a definite layer of endodermis.* (5) ***Pericycle***—*the layer* lying internal to the endodermis is the pericycle. (6) **Vascular bundles**—these are closed, collateral, and arranged in a ring. Each vascular bundle is very feebly developed with xylem on the inner side and a small patch of phloem on the outer; xylem consists of some scalariform tracheids; there is an air-passage in it. (7) **Pith cavity**—there is a big air-cavity corresponding to the pith.

Life-cycle. The life-cycle of *Equisetum* is complete in two stages—sporophytic and gametophytic. The plant itself is the sporophyte and this is followed by another structure, called prothallus, which is the gametophyte (fig. 671).

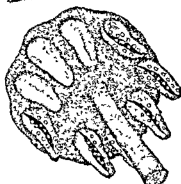
Sporophyte. The *Equisetum* plant (fig. 668) is the sporophyte, i.e it reproduces asexually by spores which are borne by specialized leaves called sporophylls.

Sporophylls, Sporangia and Spores. The sporophylls are very much specialized in structure and take the form of somewhat flattened, hexagonal or circular discs, each supported on a short stalk, and are aggregated together in whorls at the apex of usually unbranched non-green aerial shoot in the form of a *cone*, called the **sporangiferous spike** or **strobilus** (fig. 668B). The lowest whorl is sterile and forms a ring at the base of the spike. In *Equisetum*, as in all higher plants, the reproductive region is quite distinct from the vegetative region. Each sporophyll (fig. 669) has the form of a stalked peltate disc. It bears on the under-surface a group of **sporangia** (5-10) which contain numerous small **spores.** Like the fern plant, *Equisetum* is also *homosporous*, bearing only one kind of spores. Each spore contains numerous minute chloroplasts and a large central nucleus. In addition to intine and exine, the spore is provided with a third layer, called **perinium,** which, when mature, ruptures into two spirally-wound bands, called **elaters** (fig. 670), attached to the spores at their centre; the elaters appear as four distinct appendages. They are *extremely hygroscopic*; when the air is dry they unwind and stand out stiffly from the spore, and when the air is moist they roll up spirally round it. *Functions of Elaters.* The elaters expand and help the dehiscence of the sporangium. The spores become entangled by the elaters and are carried away in clusters by air-currents:



Equisetum. FIG. 668. A, a vegetative shoot with whorls of branches; *B*, a fertile shoot with a spike.

this helps the germination of spores close together for facility of fertilization.



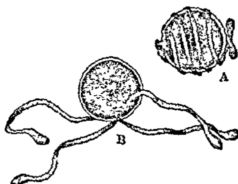


FIG. 669 FIG. 670

Equisetum. Fig. 669. A sporophyll with a whorl of sporangia. Fig. 670 Spores with elaters *A*, elaters coiled; *B*, elaters uncoiled.

Gametophyte. The prothallus (fig. 671) is the gametophyte, i.e. it bears gametes—male (antherozoid) and female (ovum),



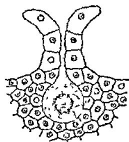


FIG. 671 FIG. 672

Equisetum. Fig. 671. Prothallus (monoecious). Fig. 672. An antherozoid (*top*) and a mature archegonium (*bottom*).

and reproduces by the sexual method. Spores remain alive only for a few days. Under favourable conditions their germi-

nation begins within 10 or 12 hours after they are set free from the sporangium. Spores can be easily grown in culture in the laboratory. On germination they give rise to prothalli which are small in size, dull brownish-green in colour and much branched (lobed). The prothalli in most species are usually 3-6 mm. in diameter; in *E. debile*, however, they may be as big as 3 cm. in diameter. Prothalli, when they grow under favourable conditions, are normally monoecious, bearing both antheridia and archegonia. If, however, they grow crowded together in the field or in culture they are dioecious, the smaller ones being male and the bigger ones female. It has been seen that the latter bear antheridia with age. This imperfect dioecism may be due to unfavourable conditions of growth. In *E. arvense*, however, about half of the spores give rise to male prothalli and the remaining half to female prothalli. If no fertilization takes place, the latter may produce antheridia. Prothalli usually live long, sometimes exceeding a period of two years. The prothallus is the **gametophyte** since it bears antheridia or archegonia or normally both. The sexual organs begin to appear in the gametophyte within 30-40 days of its growth, archegonia first and antheridia later. **Antheridia** develop at the apex of a branch (lobe) of the prothallus or on the margin of it. Each antheridium is more or less spherical in shape and contains numerous antherozoid mother-cells (usually 256). In each mother-cell one **antherozoid** or male gamete is produced. It is a large spirally coiled and multiciliated body. **Archegonia** always develop in the axial region of the prothallus and in the axil of a branch of it. Each archegonium is flask shaped with a swollen *venter* and a narrow *neck*, and contains an ovum (female gamete), a ventral canal-cell and a neck canal-cell.

Fertilization. The method of fertilization is the same as that of ferns. After fertilization the **oospore** gives rise to an **embryo** which develops into a branching rhizome. This then produces erect aerial shoots and a number of adventitious roots.

Alternation of Generations (fig. 673). *Equisetum* plant shows in its life-history a regular alternation of generations. The plant itself is the sporophyte, and the prothallus—monoecious or dioecious—is the gametophyte. As in fern, the sporophyte or *Equisetum* plant reproduces asexually by spores and gives rise to the gametophyte or prothallus, and the latter reproduces sexually by gametes—antherozoid and ovum, and gives rise to the sporophyte. Thus the two generations regularly alternate with each other. The sporophytic genera-

tion begins with the oospore and ends in the spore mother-cells because in all these stages $2n$ chromosomes are met with; while the gametophytic generation begins with the spores and ends in the gametes (antherozoid and ovum) because in all these stages there are only n chromosomes.

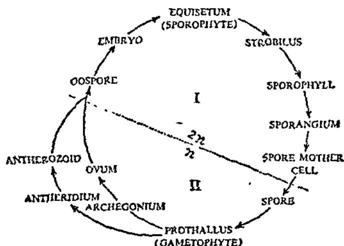


FIG. 673. Life-cycle of *Equisetum* (diagrammatic) showing alternation of generations. *I*, sporophytic generation (diploid or $2n$); and *II*, gametophytic generation (haploid or n).

3. *LYCOPODIUM* (185 sp.)

Lycopodium, commonly called club-moss, is a much-branched herbaceous plant abundantly found in the hills at a comparatively high altitude. The plant body consists of creeping rhizomes which give off slender elongated aerial branches from the upper side and adventitious roots from the lower. The branches are densely covered with numerous ... *Lycopodium* mostly shows ... nching, but some species are ... f *Lycopodium* are terrestrial while in the tropical forests there are some epiphytic species with pendent branches, e.g. *L. phlegmaria* and *L. squarrosum*. Both of them are common in Assam.

Internal Structure of the Stem. (1) **Epidermis**—a single outermost layer of small cells with the outer and often radial walls thickened and cutinized; ... region lying in ... from species to ... m (fig. 677) the ... yma, (ii) middle cortex made of sclerenchyma, and (iii) outer cortex made of one to a few layers of parenchyma or it may be absent altogether. In other species the inner cortex and the middle or outer cortex may be sclerenchymatous. (3) **Endodermis**—a single layer of small thin-walled cells surrounding the central stele; it is, however, not well-defined in all cases. (4) **Stele**—it is the



FIG. 674. *Lycopodium cernuum* (terrestrial); a sporophyll with a sporangium shown separately.



FIG. 675 FIG. 676

Fig. 675. *Lycopodium phlegmaria* (epiphytic). Fig. 676. *L. clavatum* (terrestrial); a sporophyll with a sporangium shown separately.

central cylinder of vascular system—xylem and phloem, surrounded by a few-layered thin-walled parenchyma comprising the pericycle. The stele of the *Lycopodium* stem is a *protostele* with a central vascular cylinder but no pith. There are commonly three types of stele in different species of *Lycopodium*. In some species, as in *L. serratum* and *L. phlegmaria*, xylem forms radiating arms or rays from the centre, with phloem alternating with

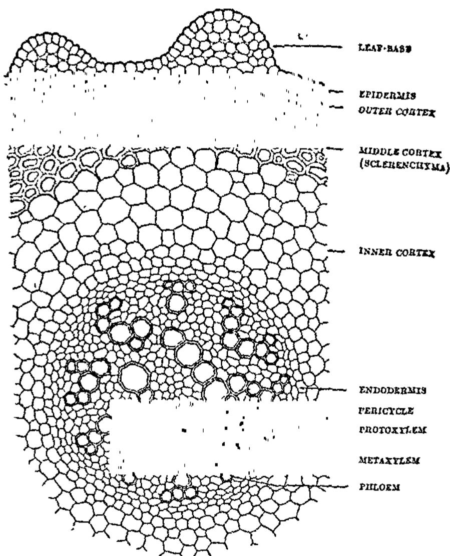


FIG. 677. *Lycopodium* (*L. cernuum*) stem in transection.

them (radial arrangement); this is called *actinostele*. In other species, as in *L. cernuum* (fig. 677), xylem is broken up into isolated strands which lie irregularly mixed with phloem; this is called *haplostele*. In still other species, as in *L. clavatum* and *L. complanatum*, xylem and phloem occur in alternating, more or less parallel bands; this is called *plectostele*. The radial type of protostele is most primitive, while the two other types are more advanced. In *Lycopodium* xylem is always exarch with protoxylem towards the pericycle, and metaxylem towards the centre. Protoxylem

consists of a few narrow annular and spiral tracheids, and metaxylem of large scalariform tracheids. Phloem consists of sieve-tubes and phloem parenchyma

Sporophyte. *Lycopodium* plant is the sporophyte, i.e. it reproduces asexually by spores which are borne by specialized leaves called **sporophylls.** The sporophylls resemble the vegetative leaves but are smaller in size. The sporophylls are aggregated together, being spirally arranged, at the apex of the vegetative branch or of special reproductive branch in the

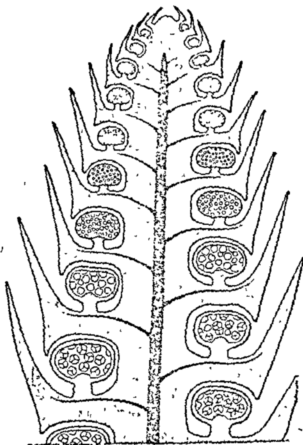
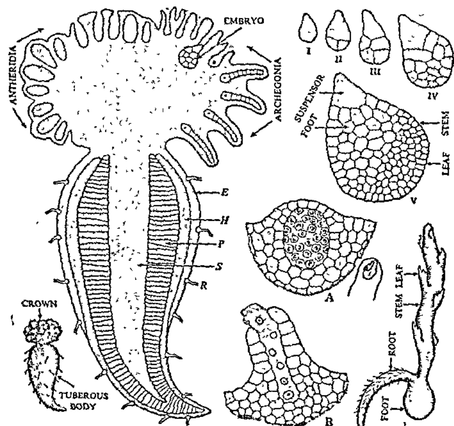


FIG. 678. *Lycopodium* spike in longitudinal section.

form of a *cone*, called ... (figs. 674-6 & 678). All the sp... also the sporangia and th... *sporous.* The sporangium has a short ... is borne on the upper surface of the sporophyll close to its base. It consists of a wall commonly made of a few (3 or more) layers of cells, and an inner mass of sporogenous cells or

spore mother-cells. By reduction division spores are formed in tetrads from these cells.

Gametophyte (figs 679-80). After dehiscence of the sporangium the spores are scattered by the wind. The spores are remarkably long-lived, often retaining their viability for a number of years. In many species the spores do not germinate within several months or sometimes even years after shedding. Even after the germination begins the rate of growth is slow. In *L. cernuum*, a common Indian species, the spores germinate within a few days and the growth of the gametophyte is completed in the same season. The spore, in any case, on germination gives rise to the gametophyte or prothallus.



Lycopodium. Fig. 679 Gametophyte. Fig. 680. The same in longitudinal section; E, epidermis; H, hyphal tissue; P, palisade tissue; S, storage tissue; and R, rhizoid. Fig. 681. Reproductive organs—A. a mature antheridium with many antherozoid mother-cells; an antherozoid on the right; B, a mature archegonium (open). Fig. 682. Stages in the development of the embryo (I-V). Fig 683. A young sporophyte (developing on the gametophyte).

The gametophyte may be subterranean or sub-aerial, and vertical or partially horizontal. In the sub-aerial type the aerial portion turns green in colour and bears the sexual organs. In size it is about 2 or 3 mm. in length. The subterraneam type is much bigger than the first type but non-green in colour. In shape the gametophyte may be a cylindrical or tuberous body with a lobed crown or it may be broad and irregularly cup-shaped. The crown bears the sexual organs. The tuberous portion shows a complicated internal structure, being differentiated into distinct regions, and is *always* associated with an endophytic (symbiotic) fungus which infects a definite region of it at an early stage of gametophyte-development. But for this fungal infection the growth of the gametophyte becomes arrested. Some rhizoids are produced from the epidermal layer. [For details see fig. 680 and the caption of it]. The gametophyte of *Lycopodium* is monoecious, bearing both antheridia and archegonia. **Antheridia and Archegonia** (figs. 680-1). Numerous antheridia and archegonia are formed in the upper lobed portion (crown) of the gametophyte. The antheridium is more or less spherical consisting of a wall made of one layer of cells and a central mass of spermatogenous cells (antherozoid mother-cells). It lies wholly or partially sunken in the tissue of the prothallus. The spermatozoids (antherozoids) are minute, broadly rounded at the base, slightly curved, and biciliated. The archegonium is a narrow elongated structure and lies almost wholly embedded in the prothallus except the upper portion of the neck which projects beyond it. It consists of a narrow venter with an egg and a ventral canal-cell, and a long neck with a variable number of neck canal-cells (1-16, commonly 4-6) which soon get disorganized.

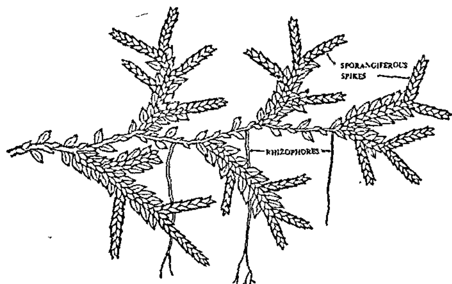
Embryo (fig. 682). After fertilization which takes place in the usual way the fertilized egg or oospore divides in two cells—outer and inner. The outer cell is the suspensor cell which is elongated but not functional, while the inner one is the embryonal cell. The latter by successive divisions gives rise to two tiers of four cells each, of which the outer tier, i.e. the one next to the suspensor, produces the foot and the inner tier produces the stem on one side and the leaf on the other side. The root develops later from the inner tier close to the leaf, and then the foot gets disorganized (fig. 683).

Alternation of Generations. *Lycopodium* plant is the sporophyte (with 2n chromosomes). It reproduces asexually by spores and gives rise to the prothallus. The prothallus

is the gametophyte (with n chromosomes). It reproduces sexually by gametes and gives rise to the sporophyte again. These two generations (sporophyte including all the stages from oospore to spore mother-cells, and gametophyte including all the stages from spores to gametes) regularly alternate with each other.

4. *SELAGINELLA* (700 sp.)

Selaginella (fig. 684) grows in damp places in the hills and in the plains. It is a slender much-branched plant creeping on the wall or on the ground. The slender stem bears four rows of leaves—two rows of small leaves on the upper surface and two rows of larger leaves at the two sides. A scaly structure, called **ligule**, develops on the upper (ventral) surface of



Selaginella. Fig. 684. A portion of a plant showing four rows of leaves, a number of spikes and three rhizophores.

each leaf above its base. A long slender root-like organ is given off from the stem at the point of bifurcation; this known as the **rhizophore** (root-bearer). In some species the rhizophore bears small fibrous roots at the tip. It has no root-cap and grows exogenously like the stem; but it resembles a true root in its internal structure and in bearing no leaves. It is regarded as a normally leafless shoot; it may bear scaly leaves and sometimes even cones.

Structure of the Stem (fig. 685). (1) **Epidermis**—a single layer with a cuticle. (2) **Sclerenchyma**—a few layers of sclerenchyma occur below the epidermis. (3) **Ground tissue**—a continuous mass of thin-walled, polygonal cells. (4) **Steles**—usually 2 or 3; each stele is surrounded by an air-space

which is formed as a result of breaking down of some of the inner layers of the cortex, and remains suspended in it (air-space) by delicate strands of cells, called **trabeculae** (sing. trabecula). Casparian strips are often present in the trabecular cells and appear as dots or thin walls. The stele, when young, is surrounded by a single-layered endodermis; later on the cells of the endodermis separate laterally and elongate considerably in the radial direction. These long radiating cells formed as a result of stretching of the endodermal cells are the trabeculae; in the mature stele they act as bridges across the air-space. Each stele which is concentric in nature consists of (a) pericycle, (b) phloem, and (c) xylem. Internal to the air-space there is

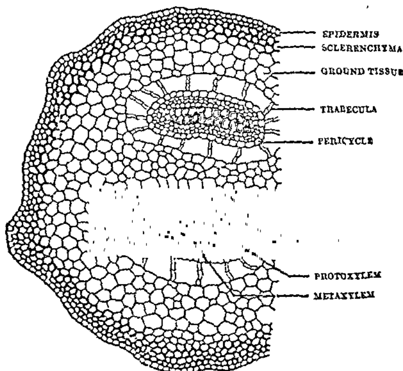


FIG. 685. *Selaginella* stem in transection

a layer, sometimes two, of rather large but thin-walled cells—the pericycle. *Phloem* surrounds the central spindle-shaped xylem. *Protoxylem* lies at the two ends and metaxylem in the middle.

Life-cycle. The life-cycle of *Selaginella* is complete in two stages—sporophytic and gametophytic, the former much more complicated and the latter much simpler than the previous cases. *Selaginella* plant is the *sporophyte and this is followed* by another *two* structures, called *prothalli*, which are the *gametophytes (male and female).*

Sporophyte. *Selaginella* plant is the sporophyte. It bears *two* kinds of spores—microspores and megaspores—and reproduces asexually by them.

Sporophylls, Sporangia and Spores. *Selaginella* bears two kinds of sporophylls—*microsporophylls* and *megasporophylls*

Both kinds of sporophylls may occur together in the same cone, or they may be borne in two separate cones either on the same plant (monoecious) or on two separate plants (dioecious). All the sporophylls are nearly of equal size and spirally arranged, usually in four rows, round the apex of the reproductive shoot, in the form of a more or less distinct four angled cone, called the **sporangiferous spike** (figs. 684 & 686-7) or **strobilus**. The sporophylls are similar to the vegetative leaves in appearance, but are smaller in size. Each megasporophyll bears in its axil a single megasporangium with usually 16 megaspore mother-cells. But only one of them divides, while others get disorganized. It undergoes reduction division and



Fig. 686

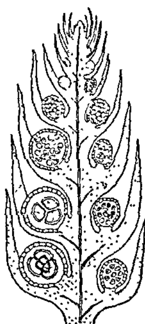


Fig. 687

Selaginella. Fig. 686. Portion of the plant with three spikes. Fig. 687. A spike in longitudinal section showing megasporophylls with megasporangia and megaspores, and microsporophylls with microsporangia and microspores.

forms a tetrad of spores (fig. 688A). Thus the megasporangium contains *four large* **megaspores**. A considerable amount of food material, chiefly oil, is stored up in the megaspore. The microsporophyll similarly bears in its axil a microsporangium with usually 16 microspore mother-cells. All of them undergo reduction division and give rise to 64 *small* **microspores** (fig. 691A) in groups of four (tetrads). *Selaginella* is thus **heterosporous**. The sporangia consist of a short stout stalk and a capsule; the wall of the capsule is composed of three

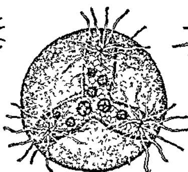
layers of cells. The megasporangia are somewhat larger than the microsporangia.

Gametophytes. The two prothalli (male and female) are the gametophytes, i.e. they bear male gametes or antherozoids and female gamete or ovum, and reproduce sexually by them.

Germination of the Megaspore: Female Prothallus (figs. 689-90). The megaspore-nucleus divides repeatedly by the process of free cell formation (see fig. 387) and gives rise to a mass of tissue within it. This is the female prothallus, i.e. the female gametophyte (fig. 689). *The megaspore begins to grow before it is set free from the megasporangium*, but the formation of the female gametophyte is completed after the spore has fallen to the ground. At an early stage of gametophyte formation a cavity appears at one end of it and is filled with reserve food, chiefly oil. This cavity subsequently becomes filled with cells. Further development of the gametophyte exerts pressure on the spore-wall which ruptures by a tri-radiate fissure, and the gametophyte becomes partially exposed (figs 689-90). *The gametophyte is partially endosporous. It is a much-reduced structure* compared to that of fern or *Equisetum*. It is also *not an independent structure* like that of fern or







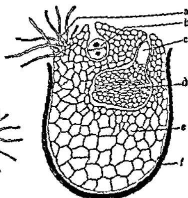


FIG. 688 FIG. 689 FIG. 690

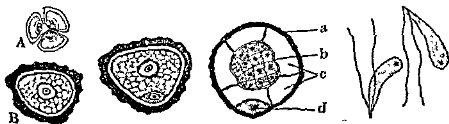
Selaginella. Megaspore and Development of Female Prothallus. Fig. 688. A, megaspores in a tetrad; B, a megaspore *in section*. Fig. 689. Germinating megaspore with female prothallus protruding through the tri-radiate fissure of the wall. Fig. 690. Female prothallus in longitudinal section. *a*, rhizoids; *b*, oospore after first division; *c*, suspensor; *d*, embryo; *e*, tissue of the prothallus; and *f*, wall of the megaspore.

Equisetum, being enclosed by the spore-coat and nourished by the food stored in the spore. *A number of archegonia* and some groups of rhizoids develop in the exposed green portion of the prothallus, while food is stored up in the inner

non-green portion of it. Each archegonium is also reduced in size, consisting of a short neck with one neck canal-cell, and a venter with an ovum and a ventral canal-cell.

Germination of the Microspore: Male Prothallus (figs. 691-3). The microspore germinates and gives rise to the male prothallus, i.e. the male gametophyte. It begins to divide after it is set free from the microsporangium. A small cell is cut off at one end of the microspore; this is the **prothallus cell** representing an extremely reduced male gametophyte. The rest of the microspore forms a single **antheridial cell** which by a series of divisions forms a small mass of cells. These are differentiated into a layer of peripheral sterile cells—the **jacket cells**, enclosing about 128 to 256 **antherozoid mother-cells.** Each mother-cell encloses a single biciliated slightly twisted **antherozoid** or male gamete (fig 694).

Fertilization. After fertilization, which is essentially the same as in fern and *Equisetum*, the ovum becomes the



Selaginella. Microspore and Development of Male Prothallus. Fig. 691. *A*, microspores in a tetrad; *B*, a microspore in section. Fig. 692. Germinating microspore with prothallus cell. Fig. 693. Male prothallus in section. *a*, wall of microspore; *b*, antherozoid mother-cells; *c*, jacket cells; and *d*, prothallus cell. Fig. 694. Two antherozoids.

oospore; the latter divides and forms the **embryo** which gradually develops into the *Selaginella* plant. Thus the life-history is completed.

Alternation of Generations *(fig. 695). The life-history of Selaginella* shows that the plant passes through two generations which regularly alternate with each other. The plant itself is the sporophyte, and the two prothalli—male and female—are the gametophytes. The sporophyte reproduces asexually by two kinds of spores—microspore and megaspore—which give rise to the male prothallus and the female prothallus respectively. The male prothallus bears antherozoids

in the antheridium, and the female prothallus bears the ovum in the archegonium, and the two prothalli (gametophytes) reproduce sexually by these two gametes, giving rise to the

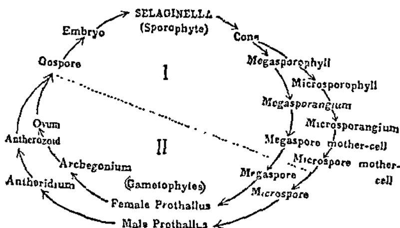


FIG. 695. Life-cycle of *Selaginella* (diagrammatic) showing alternation of generations. *I*, sporophytic generation (diploid or $2n$), and *II*, gametophytic generation (haploid or n).

sporophyte again. The two gametes fuse together and give rise to the oospore. The oospore is the beginning of the sporophytic generation because $2n$ chromosomes are met with for the first time in the oospore, and all the stages from the oospore to the spore mother-cells represent the sporophytic generation. Reduction division takes place in the formation of the spores; so all the stages from the spores to gametes (antherozoid and ovum) with n chromosomes represent the gametophytic generation.

PART VI

GYMNOSPERMS

CHAPTER I

GENERAL DESCRIPTION

Spermatophytes (or 'seed' plants) or **phanerogams** (or 'flowering' plants) are divided into two sub-divisions—**angiosperms** (*angeion*, case; *sperma*, seed) and **gymnosperms** (*gymnos*, naked). Gymnosperms are closely related to the higher cryptogams on the one hand and to the angiosperms on the other, and thus they form an intermediate group between the two. It should be noted that lower gymnosperms like cycads have greater affinities with the higher cryptogams, while the higher gymnosperms like pines (and *Gnetum*) with the angiosperms. Salient points of resemblances and differences are given below. Gymnosperms number about 700 species.

Gymnosperms and Higher Cryptogams

Resemblances

1. Identical nature of general life-history in both with, of course, structural differences; both the groups show a regular alternation of generations with gradual reduction and loss of independence of gametophyte from higher cryptogams to gymnosperms, and gradual increase in the complexity of the sporophyte.

2. Differentiation of the plant body into root, stem and leaves.

3. Compound nature of leaves and circinate vernation, as in earlier gymnosperms (cycads).

4. Xylem of the vascular bundle with only tracheids (and no vessels) and phloem without companion cells are characteristic of both the groups.

5. Gradual differentiation of sporophylls (micro- and mega) and of spores—microspore and megaspore (heterosporous condition) in the higher cryptogams leading to the complete differentiation of the same in the gymnosperms, and the segregation of the sporophylls from the vegetative region, and their arrangement in the form of cones (strobili).

6. Development of the gametophyte within the spore-coat as a dependent body (partially endosporous in *Selaginella* but completely endosporous in gymnosperms) for advantages of food supply and adequate protection by the sporophyte.

7. Development of ciliated spermatozoids in lower gymnosperms (cycads), as in cryptogams.

8. Retention of the megaspore within the megasporangium (permanently in gymnosperms but for a short period only in *Selaginella*) and the development of the archegonia in the female gametophyte.

9. Formation of the suspensor in gymnosperms during the stages of embryo development, as in *Selaginella*.

Differences

1 Development of the ovule (and later the seed) makes a fundamental difference between the gymnosperms and the cryptogams. The ovule and the seed are *characteristic* of all gymnosperms, while these are altogether absent in cryptogams

2. Formation of the pollen-tube in gymnosperms is another special feature which is conspicuous by its absence in cryptogams. The pollen-tube carries the non-motile male gametes to the archegonium in most of the gymnosperms, while in all cryptogams the motile spermatozoids by themselves *swim to the archegonium* in a drop of water. In *Cycas*, however, the pollen-tube is a sucking organ (haustorium) and not a sperm-carrier.

3. The megasporangium of the gymnosperm is not shed before fertilization and maturity; further it is provided with a new structure in the form of a coat—the integument The megasporangium covered by the integument is the ovule. The ovule is altogether absent in cryptogams

4 The
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enclosed *within the* megasporangium and is nourished by the latter.

5. Remaining enclosed the gametophytes of gymnosperms are also *not* green in colour.

6. Archegonia are much simpler in construction in *gymnosperms with shorter neck* and no neck canal-cells, unlike cryptogams Final reduction of archegonia in higher gymnosperms, as in *Gnetum*,—a condition more akin to angiosperms.

7. Presence of the cambium in gymnosperms leading to secondary growth in thickness, and absence of it in cryptogams with *no secondary growth* Besides, *tracheids* with circular pits and those with scalariform markings are characteristic of gymnosperms and higher cryptogams respectively.

Gymnosperms and Angiosperms

Resemblances

1. The plant body is differentiated into distinct root and shoot, the latter with copious branches and leaves, however small they may be. In habit the plants of both the groups may be shrubs and trees, with preponderance of angiospermic herbs.

2. Vascular system is well developed in both, with xylem and phloem (note, however, their differences, as given at p. 495).

3. Flowers are developed in both cases for reproduction But gymnospermic flowers are primitive in nature and simple in construction and are always unisexual and without perianth. Angiospermic flowers are, however, more advanced with often both sepals and petals Gymnospermic flowers are pollinated through the agency of air-currents only, while angiospermic flowers are pollinated through various agencies, particularly insects.

4. Microspore or pollen grain grows into a pollen-tube which carries the male gametes to a position close to the female gamete or ovum for the purpose of fertilization In *Cycas*, however, the pollen-tube is *branched* penetrating into the nucellus and acts as a sucking organ (haustorium) and not as a sperm-carrier.

5 The megaspore remains permanently enclosed in the megasporangium (nucellus of the ovule) and it germinates into the female gametophyte or embryo-sac (reduced prothallus) within the megasporangium.

6. The megasporangium remains enclosed by the integument or seed-coat (1 in gymnosperms and usually 2 in angiosperms) giving rise to a more complicated structure known as the ovule (and later the seed) for better protection of the embryo.

7. The young sporophyte (embryo) develops at the expense of the food stored up in the parent sporophyte.

Differences

1. In angiosperms xylem is mainly composed of vessels, and phloem contains companion cells; while in gymnosperms xylem is exclusively made of tracheids, and phloem contains no companion cells. In higher gymnosperms, however as in *Gnetum*, there is a combination of gymnospermic tracheids and angiospermic vessels.

2. Flowers are much simpler in gymnosperms; no calyx or corolla is present; also the flowers are always unisexual consisting of either microsporophylls (stamens) or megasporophylls (carpels) only, and the plants either monoecious or dioecious In gymnosperms stamens and carpels are much simpler in construction than in angiosperms The sporophylls in gymnosperms are borne in strobili (except the megasporophylls of cycad), whereas in angiosperms these are borne in flowers

3. For pollination in gymnosperms the only agency is air-current, while in angiosperms there are many different pollinating agents.

4 Ovules in gymnosperms are borne freely exposed on the megasporophyll (carpel); while in angiosperms the ovules remain enclosed in the ovary, the carpel itself being differentiated into ovary, style and stigma.

5. For pollination in gymnosperms pollen grains enter the micropyle and directly lodge on the nucellus, whereas in angiosperms these are deposited on the stigma.

6. In angiosperms and higher gymnosperms the male gametes contained in the pollen-tube are two passive units, but in lower gymnosperms (*Cycas*, *Zamia* and *Ginkgo*) the male gametes are in the nature of ciliated spermatozoids.

7. In gymnosperms the male gametophyte is represented by a few cells (usually 2 or 3)—a vestigial protnallus; while in angiosperms it is reduced to two nuclei only—the tube nucleus and the generative nucleus; in fact there is very little evidence of a male prothallus in angiosperms.

8 The female gametophyte in gymnosperms is a relatively large structure with distinct archegonia embedded in it, each with an ovum; while in angiosperms the female gametophyte is a vestigial prothallus represented by an 8-nucleate embryo-sac, and the ovum or egg-cell is free in it without any archegonium.

9. The endosperm, when present in the angiosperm, is formed from the definitive nucleus only after fertilization and is triploid in nature; while in gymnosperms the endosperm is formed from the vegetative tissue of the female prothallus before fertilization and is haploid in nature. Endosperm formation is, however, completed after fertilization, the seeds in all gymnosperms are endospermic.

Homologous Structures in Cryptogams and Phanerogams

Megasporophyll	= Carpel	Microsporophyll	= Stamen
Megasporangium	= Nucellus of the ovule	Microsporangium	= Pollen-sac
		Microspore	= Pollen grain
Megaspore	= Embryo-sac mother-cell	Male gametophyte	= Germinating pollen grain (pollen-tube and three nuclei in it).
Female gametophyte	= Embryo-sac		

Development of the Seed in Gymnosperms. The seed makes its appearance for the first time in gymnosperms. It develops

from the ovule and the following factors are responsible for its development.

1. Heterospory and differentiation of sporophylls and sporangia are the initial factors, as we find in *Selaginella*, leading towards seed production in the future.

2. Retention of the megaspore within the megasporangium (nucellus of the ovule) and its germination into the female gametophyte (embryo-sac) within the megasporangium so that it (the female gametophyte) becomes completely endosporous; it is partially endosporous in *Selaginella*.

3. Enclosure of the megasporangium and the female gametophyte within a new structure, i.e. the *integument*,—the whole complex body so formed being known as the *ovule*. This ovule after fertilization and maturity gives rise to the seed.

4. Attachment of the megasporangium (and the ovule) to the megasporophyll till after its development into the seed.

5. Development of the young sporophyte (embryo) within the tissue of the megasporangium (nucellus) which belongs to the mother sporophyte, ensuring better feeding and greater protection.

6. Development of the pollen-tube for facility of fertilization under the new condition of ovule formation.

It is thus evident that the seed of the gymnosperm is a complex structure with three generations locked up in it: (1) the seed-coat or testa representing the parent sporophyte (old generation), (2) the female gametophyte representing the present generation, and (3) the embryo representing the new sporophyte (future generation).

Classification. Gymnosperms comprise six orders of which two have become extinct and the other four are living; these are (1) Cycadales (represented by the family *Cycadaceae*), (2) Ginkgoales (represented by the family *Ginkgoaceae* with one genus and one species in China and Japan), (3) Coniferales (represented by six families, e.g. *Taxaceae*, *Pinaceae*, etc., with altogether 41 genera and about 400 species), and (4) Gnetales (represented by the family *Gnetaceae*). An outline of classification is given in the following schedule:

	Order	Family	Example
Gymnosperms	Cycadales —	*Cycadaceae*,	e.g. cycad (*Cycas*)
	Ginkgoales —	*Ginkgoaceae*,	e.g. *Ginkgo*
	Coniferales —	*Taxaceae*,	e.g. yew (*Taxus*)
		Pinaceae,	e.g. pine (*Pinus*)
	Gnetales —	*Gnetaceae*,	e.g. *Gnetum*

CHAPTER II

CYCADALES

The family *Cycadaceae* (commonly called cycads) comprises 9 genera with about 75 species. The genus *Cycas* is represented in India by a few species, of which *C. revoluta* and *C. circinalis* are fairly common in the hills, and both yield a kind of sago. *C. pectinata* is common in the hills of Assam.

CYCAS (16 sp)

The stem of **cycad** (*Cycas*; fig. 696) is unbranched erect stout and palm-like, with a crown of pinnate leaves arranged spirally round the apex. Besides, there are small dry scale-like leaves alternating with the green pinnate leaves. Vernation (ptyxis) of the leaf is circinate like that of ferns. The plant has a long primary (tap) root.

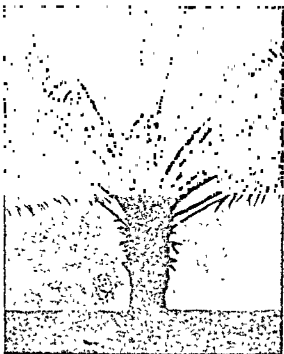
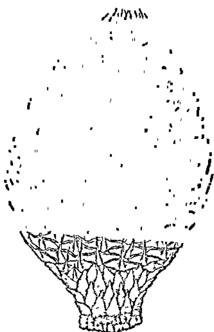


FIG. 696. A female plant of *Cycas circinalis* with carpels.

Cycads are dioecious, i.e. male and female flowers are borne by two separate plants. The male flower is a cone (fig. 697) borne at the apex of the stem which then grows by a lateral bud (the stem becomes a sympodium). The male cone consists of a collection of **stamens** or **microsporophylls** arranged spirally round the axis. Each sporophyll (fig. 700) is in the form of a scale, narrowed below and broadened above. It bears on its under-surface several **pollen-sacs** or **microsporangia** grouped in sori. There are usually 2 to 6 pollen-sacs in each sorus. In each pollen-sac there are numerous **pollen grains** or **microspores**. Each microspore before it sheds from the microsporangium or pollen-sac produces

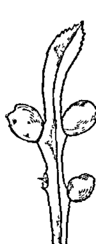
within it a male prothallus (fig. 703). This is the male gametophyte. It consists of a vegetative (prothallus) cell, a generative cell and a tube cell.

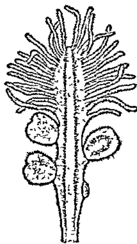
In *Cycas* there is no proper female flower; the plant bears near its apex a rosette of **carpels** or **megasporophylls** (figs. 698-9) which do not form a cone but are arranged alternating with the leaves. They are usually 6-12 inches long, flattened or bent over like a hood, and often dilated above. In many species they are covered all over with soft brownish hairs. The margin may be entire, crenate or pectinate (pinnately divided). Ovules, usually 2-3 pairs, sometimes up to 5 pairs, are borne in an alternate or opposite manner in notches on either side of the stalk. In gymnosperms the carpel is always open, i.e. it does not close up, as in angiosperms, to form the ovary, style and stigma, and the ovules are borne, freely exposed, on the two margins of the carpel. The ovule (fig. 701) grows considerably even before fertilization. It consists of a single thick integument and a nucellus or megasporangium fused practically throughout with the integument. The integument has an apical opening—the micropyle, and it consists of three layers—a middle stony layer and a fleshy layer on either side. Within the megasporangium a megaspore mother-cell is produced and it divides to form a row of four megaspores. Only one megaspore is functional; while others disintegrate. The functional megaspore grows rapidly and more or less completely fills up the nucellus. Inside the megaspore a cellular mass of tissue is formed. This is known as the female prothallus (designated as endosperm). The endosperm grows quickly after fertilization and forms the major part of the seed. This represents the female gametophyte. It produces towards the micropyle a few (3-6) archegonia. Each archegonium (fig. 702) consists of two neck cells but no neck canal-cell and a free



Cycas. FIG. 697. A male cone of *Cycas pectinata* consisting of innumerable microsporophylls arranged spirally round the stout axis.

large egg-nucleus. The ventral canal-cell is represented only by a nucleus which, however, soon gets disorganized. Just





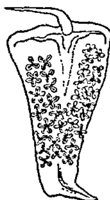
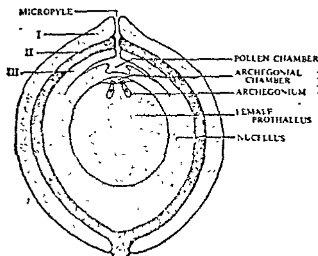


FIG. 698 FIG. 699 FIG. 700

Cycas: Carpels and Stamen. Fig. 698. A carpel or megasporophyll of *Cycas circinalis*. Fig. 699. A carpel or megasporophyll of *Cycas revoluta*. Fig. 700. A stamen or microsporophyll of *Cycas pectinata* with numerous pollen-sacs or microsporangia on the under-surface (slightly oblique view).

below the micropyle a chamber or cavity is formed due to the breaking down of some of the nucellus cells. This cavity



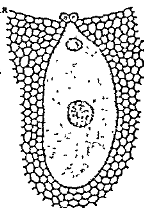


FIG. 701 FIG. 702

Cycas. Fig. 701. Ovule in longitudinal section; *I*, *II* and *III*, outer, middle (stony) and inner layers of the integument. Fig. 702. An archegonium.

is called the pollen-chamber. Just below this another chamber is formed in the prothallus. This is the archegonial chamber.

Pollination and Fertilization. Pollen grains are carried by the wind. They fall on the micropyle and get bathed in the mucilage secreted by the latter; as the mucilage dries up the pollen grains are drawn into the pollen-chamber. The tube-cell elongates into a long branched pollen-tube (fig. 704) which penetrates into the nucellus. The pollen-tube of *Cycas* is a sucking organ (haustorium) absorbing food from the nucellus, *and is not a sperm-carrier.* The generative *cell divides* into two—the stalk cell and the body cell. The stalk cell is sterile and the body cell divides into two large top-shaped multiciliated male gametes (**spermatozoids**; fig. 705). The pollen-tube bursts at the apex and the spermatozoids are set free. They enter the archegonium and one of them fuses with the egg-nucleus. Fertilization is thus effected.

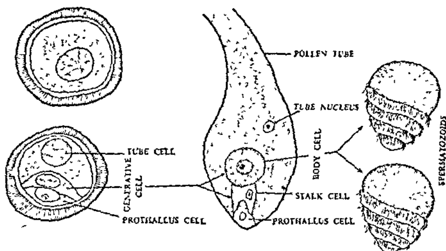


FIG. 703 FIG 704 FIG. 705

Cycas. Fig. 703. *Top,* a pollen grain or microspore; *bottom,* male prothallus. Fig. 704. Pollen-tube (a portion). Fig 705. Two spermatozoids.

Seed. After fertilization the egg-cell grows into an embryo, and the ovule as a whole into the seed. The mature seed bears only one embryo with *two* cotyledons lying embedded in the prothallus (endosperm) which again is surrounded by the integument. Prothallus stores a considerable quantity of food for the embryo to be utilized at the time of germination.

CHAPTER III

CONIFERALES

Coniferales (coniferae or conifers) constitute the largest order among the gymnosperms and comprise six families, e.g.

Taxaceae, Pinaceae, etc., which are represented by 41 genera and about 400 species. They mostly grow in cold climates and at high altitudes in the hills, and are evergreen trees or shrubs. *Taxaceae* is represented by 4 genera and 18 species, of which yew (*Taxus*) is the typical genus, and *Pinaceae* is represented by 9 genera and about 130 species, of which pine (*Pinus*), fir (*Abies*), Atlantic cedar (*Cedrus atlantica*), Himalayan deodar (*Cedrus deodara*), etc., are some of the genera. *Pinus* is, of course, the typical genus of *Pinaceae*.

PINUS (70 sp).

Pine (*Pinus*; figs. 708-9) is a tall tree with a well-developed tap root and numerous aerial branches. Common species of *Pinus* are *P. khasya, P. sylvestris, P. longifolia, P. excelsa,* etc. Leaves of *Pinus* are of two kinds—long green needle-like foliage leaves and small brown scaly leaves. Shoots are also of two kinds—long (of unlimited growth) and dwarf (of limited growth). [See caption of fig. 708.]

Internal Structure of the Young Stem. It resembles the dicotyledonous stem in many respects The general arrangement of the various tissues from the circumference to the centre is the same It differs, however, from the latter in having a large number of resin-ducts filled with brownish contents, i e. resin These ducts are to be seen distributed almost throughout the stem. The epidermis has an irregular outline Endodermis and pericycle are like those of the dicotyledonous stem, but the pericycle contains no sclerenchyma. The vascular bundles are not wedge-shaped, as in the dicotyledons. Phloem consists of sieve tubes and phloem parenchyma, but no companion cells Protoxylem consists of annular and spiral tracheids which are irregularly disposed towards the centre. Metaxylem consists exclusively of tracheids with bordered pits These (tracheids) are arranged in radial rows as seen in a transverse section of the stem. The pits of the coniferous wood are large and mostly restricted to the radial walls; while in angiosperms these are much smaller but more numerous, and are not confined to particular walls. There are no true vessels in the coniferous stem.

1. **Epidermis.** A single layer with a very thick cuticle, and an irregular outline 2 **Sclerenchyma.** Sometimes a few patches of sclerenchyma occur here and there below the epidermis. 3. **Cortex.** Many layers of more or less rounded cells, with conspicuous resin-ducts lying embedded in the cortex. 4. **Endodermis.** A single layer lying internal to the cortex, but not well marked off from the latter 5 **Pericycle** is only parenchymatous; there is no sclerenchyma in it. 6. **Medullary Rays.** These run from the pith outwards between the vascular bundles. 7. **Pith.** There is a well-defined pith, consisting of a mass of parenchymatous cells. A few resin-ducts are also present in the pith 8 **Vascular Bundles.** These are collateral and open, and arranged in a ring, as in the stems of dicotyledons. Each bundle consists of phloem, cambium and xylem. (*a*) **Phloem** consists of sieve-tubes and phloem parenchyma, but no companion cells It lies on the outer side of the bundle (*b*) **Cambium.** A few layers of thin-walled, rectangular cells lying in between xylem and phloem. (*c*) **Xylem** consists exclusively of tracheids; there are no true vessels in the wood. Resin ducts are also present here. Protoxylem lies towards the centre and consists of a few annular and spiral tracheids which are not

disposed in any regular order. *Metaxylem* lies towards the cambium, and consists of tracheids with bordered pits which develop on the radial walls. These tracheids are roughly four-sided and are arranged in definite rows.

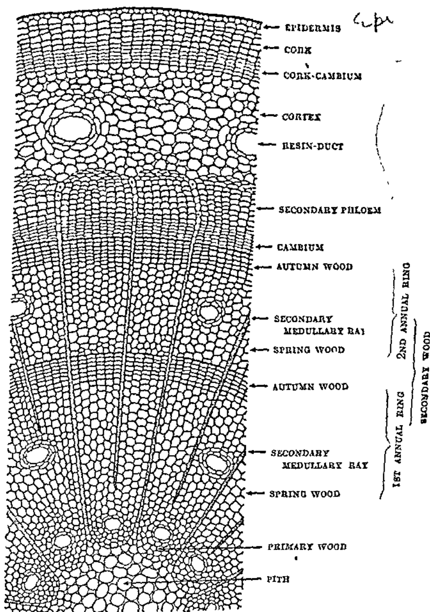


FIG. 706 A two-year old pine stem in transection (a sector).

Secondary Growth in Thickness of the Stem (fig 706) The secondary growth in a coniferous (pine) stem takes place in exactly the same way as in a dicotyledonous stem. The following points may, however, be mentioned here, showing slight differences between the two

The coniferous (pine) stem is characterized by the presence of conspicuous resin-ducts which are distributed almost throughout the stem. The

secondary wood consists exclusively of tracheids with numerous bordered pits on their radial walls. As in the dicotyledonous stem, there are distinct annual rings, consisting of the autumn wood and the spring wood, the former consists of narrow and thick-walled tracheids, and the latter of wider and thinner-walled tracheids. The secondary medullary rays are usually one layer of cells in thickness and a few in height. The phloem portion of the medullary ray consists of middle layers of starch-containing cells, called *starch cells*, and upper and lower layers of protein-containing cells, called *albuminous* cells; the xylem portion of the same consists of similar *starch cells* in the middle, and empty cells with bordered pits, called *tracheidal cells*, in the upper and lower layers. Vessels or fibres are absent.

Internal Structure of the Pine Needle (fig. 707). (1) **Epidermis**—a single layer of very thick-walled cells with a strong cuticle; the cell-cavity is nearly obliterated. There are stomata sunken to some extent in this layer, each stoma opening internally into a respiratory cavity. (2) **Sclerenchyma** occurs internal to the epidermis in 1, 2 or 3 layers interrupted by the stomata. This tissue is deeper at the ridges. (3) **Mesophyll** consists of large thin-walled polygonal or irregular cells containing abundant chloroplasts. There are peg-like projections of the cell-walls into the cell-cavity.



FIG. 707. Pine leaf in transection, as seen under a microscope.

In the mesophyll there are some resin-ducts here and there. Each resin-duct is surrounded by a layer (epithelium) of thin-walled cells. (4) **Endodermis** occurs as a conspicuous layer of large barrel-shaped cells. (5) **Pericycle** lies internal to the endodermis and is a many-layered tissue It consists of some parenchyma, often some sclerenchyma, particularly on the phloem side, and transfusion tissue. **Transfusion tissue** consists of (*a*) *albuminous cells* which are parenchymatous in nature, living and rich in protein and starch, and (*b*) *tracheidal cells* which are thin-walled elongated dead cells, but

provided with bordered pits like tracheids. Albuminous cells serve to conduct food from the mesophyll to the phloem, and tracheidal cells to conduct water and mineral salts from the xylem to the mesophyll. (6) Vascular bundles are two in number and collateral (closed). *Xylem* consisting of rows of tracheids lies towards the angular ride of the leaf, and phloem consisting of sieve-tubes lies towards the convex side.

Pinus, like all other gymnosperms, is the sporophyte. It bears two kinds of sporophylls—microsporophylls and megasporophylls (cf. *Selaginella*). These are collected together at the apex of the shoot into two separate cones, called the flowers. Cones always develop on the shoots of the current year, the male ones (fig. 708) near their apex grouped together in spikes, and the female ones (fig. 709) lower down, either solitary or in a whorl. Flowers have no perianth.

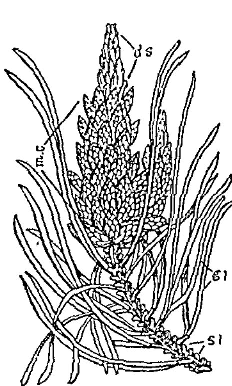


FIG. 708

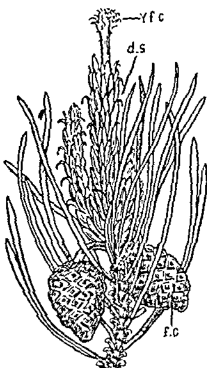


FIG. 709

Pinus. Fig. 708. A shoot of unlimited growth with young male cones. At the apex is the terminal bud. A group of lateral buds may also be seen very near the apex in winter. *Each lateral bud gives rise to a long shoot in the spring. Near the apex* a number of young dwarf shoots (*d. s*) are produced, each *in the axil* of a scale. *Each dwarf shoot, as it grows*, bears a few scale leaves at the base and two or more green *needle*-like leaves. The green leaves are borne *on dwarf shoots only*, and not directly on the long shoot; the scale leaves are borne both on long and dwarf shoots. Below the young dwarf *shoots a group of male* cones (*m.c*) are seen; *g.l*, green leaves; *s l*, scale leaves.

Pinus. FIG 709. A similar shoot with female cones *y.f c*, young female cone; *d s*, dwarf shoots; *f.c*, female cone (mature)

Male Cone (figs. 708 and 710). The male cone bears a number of spirally arranged **microsporophylls or stamens.** Each microsporophyll (fig. 711) is differentiated into a stalk (filament) and a terminal leafy expansion (anther). It bears on its under-surface two pouch-like **microsporangia** or **pollen-sacs** (figs. 711-3). In some conifers these may be as many as 15. Each pollen-sac is filled up with numerous **pollen grains** or **microspores.** Each pollen grain has two coats—outer and inner, respectively known as *exine* and *intine*. The exine forms two wings (fig. 716) on the two sides of the pollen grain. A huge quantity of pollen is produced for pollination to be brought about by wind.

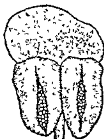
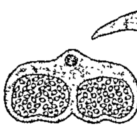
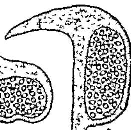
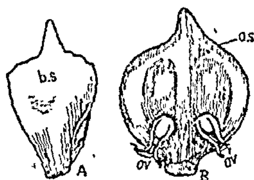





Fig. 710 Fig. 711 Fig. 712 Fig. 713

Pinus. Fig 710. A male cone in longitudinal section. Fig. 711. A microsporophyll showing two microsporangia (pollen-sacs). Fig. 712. The same in transection Fig. 713. The same in longitudinal section. Note the microspores (pollen grains) with wings.

Female Cone (figs. 709 and 719). Each female cone consists of a short axis round which a number of small dry brownish scales, slightly fringed at the upper part, are spirally arranged. These are known as the **bract scales or carpellary scales** (fig. 714A) corresponding to the carpels or megasporophylls. They are inconspicuous in the mature cone. On the upper surface of each bract scale there is another stouter scale, woody in nature, known as the **ovuliferous scale** (fig. 714B), much bigger than the former. This is variously interpreted as an open carpel, a placenta or a ligular outgrowth. At the base of each ovuliferous scale, lying on its upper surface, there are two ovules with their micropyles turned downwards towards the axis of the cone. Each ovule (fig. 715) consists of a central

mass of tissue—the nucellus . . . . . , surrounded by a *single* int . . . . ide. Within the nucellus a . . . . is produced and it divides to form a *row of four* megaspores. Only one megaspore is functional; while the *other three* degenerate.



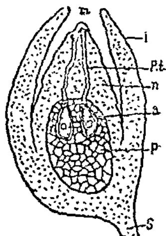


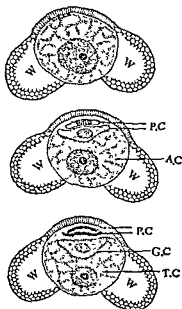
FIG. 714 FIG. 715

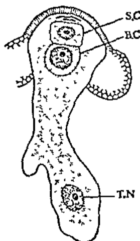
Pinus. Fig. 714. Megasporophyll. *A*, lower surface showing bract scale (*b.s.*); *B*, upper surface showing ovuliferous scale (*o.s*) and ovule (*ov*). Fig. 715. Ovule in longitudinal section. *m*, micropyle; *i*, integument; *P.t*, pollen-tube; *n*, nucellus; *a*, archegonium; *P*, prothallus (endosperm); *S*, *stalk*.

Male Gametophyte (fig. 716). The microspore or pollen grain begins to divide before it is set free from the microsporangium or pollen-sac and gives rise to the extremely reduced male prothallus (gametophyte) within the microspore coat. The prothallus consists of (*a*) 2 or 3 small cells (**prothallus cells**) which soon get disorganized, and (*b*) an **antheridial cell** which is the remaining large cell of the prothallus. The antheridial cell divides and forms a **generative cell** and a **tube cell.** The pollen grain sheds at this stage and subsequent changes take place after pollination

Female Gametophyte (fig. 715). The megaspore germinates *in situ* before fertilization and gives rise to the female prothallus within the nucellus. The female prothallus, designated as the endosperm, remains permanently enclosed within the nucellus. The endosperm grows quickly after fertilization and covers up the embryo in the seed. Lying embedded in the prothallus there are 2-5 **archegonia** which are very much like those of *Selaginella.* As in the latter, each archegonium consists of a neck and a venter. The venter encloses a large **egg-nucleus,** and also a ventral canal-cell which soon gets disorga-

nized. The neck consists of 2 or more neck-cells but no neck canal-cell. The ovules are mostly orthotropous in the gymnosperms.





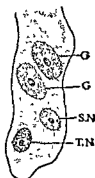


FIG. 716 FIG. 717 FIG. 718

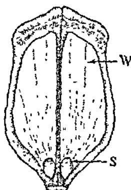
Pinus FIG. 716. Pollen and male gametophyte. Fig. 717. Pollen-tube. Fig. 718. Lower portion of the pollen-tube. *W*, wing; *P C*, prothallus cells; *A.C*, antheridial cell; *G.C*, generative cell; *T.C*, tube cell; *S.C*, stalk cell; *B.C*, body cell; *T.N*, tube nucleus, *G*, male gamete; and *S.N*, stalk nucleus.

Pollination. Pollination takes place in the same way, as in angiosperms. Pollen grains or microspores being provided with wings are easily carried by the wind to the female cone. A huge quantity is, however, wasted. They pass between the two slightly opened scales and are deposited at their base. A quantity of mucilage is secreted at the micropyle in which the microspores get entangled. After pollination the scales close up and so does the wide gaping integument. The mucilage is drawn in by the nucellus together with the microspores. The latter then lodge at the apex of the nucellus. Pollination takes place in May or June—much earlier in the plains—but fertilization is usually brought about in the following year at about the same time, and in the third year the cone is mature.

Fertilization. The mode of fertilization in *Pinus* was first discovered in 1883, and the process is as follows. After pollination the outer coat (exine) of the pollen grain bursts and

the inner coat (intine) grows out into a slender tube, i.e. the pollen-tube (figs. 617-8) which passes through the nucellus and reaches the archegonium. The pollen-tube is characteristic of all gymnosperms and angiosperms. The tube nucleus passes into the pollen-tube. The generative cell divides and forms a





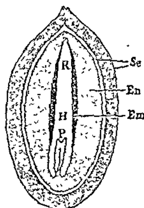


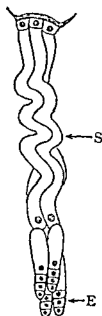
FIG. 719 FIG. 720 FIG. 721

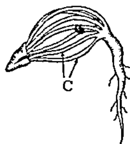
Pinus. Fig. 719. A mature female cone. Fig 720 A *mature megasporophyll* with two seeds (winged); *S*, seed; *W*, wing. Fig. 721. A seed in longitudinal section; *P*, plumule *with many cotyledons*; *H*, hypocotyl; *R*, radicle; and *Se*, seed-coat, (with outer and inner fleshy layers and middle stony layer); *En*, endosperm; and *Em*, embryo.

stalk cell and a **body cell.** Both these cells migrate into the pollen-tube. The stalk cell is sterile and the body cell divides and produces two **male gametes.** The male gametes are not ciliated, as in cycads. The pollen-tube bursts at the *apex* and only one of the two male gametes fuses with the egg-nucleus. The fertilized egg clothes itself with a cell-wall and becomes the oospore.

Seed. After fertilization the megasporophylls grow *considerably and so do the ovules.* The whole female *flower develops* into a fruit called the **cone** (fig. 719). *The cone* is woody in *Pinus.* The oospore grows and gives rise to a group *of* four embryos (fig. 722). Besides, as there are a few archegonia *in* the ovule, many embryos may be formed. This **polyembryony** (see p. 372) *is characteristic of coniferae ; but ultimately* one embryo comes to maturity, while *others* die off. The embryo consists of a number of cotyledons (2 *to* 15), a radicle and a tiny plumule (figs. 721 and 723). The ovule as a whole grows and matures into the seed (figs. 720-1). The seed is provided with a membranous wing. *In all gymnosperms* the seed is

albuminous and provided with one seed-coat. Under suitable conditions the seed germinates (figs. 723-4). The cotyledons





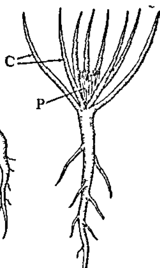


FIG. 722. FIG. 723 FIG. 724

Pinus. Fig. 722. Development of the embryo; *S*, suspensory cells; and *E*, embroys. Fig. 723. Germination of the seed; *C*, cotyledons. Fig. 724. A seedling; *C*, cotyledons; and *P*, plumule.

are pushed upwards, germination being epigeal, and they turn green in colour. The radicle grows downwards into the tap root, and soon the seedling becomes established.

CHAPTER IV

GNETALES

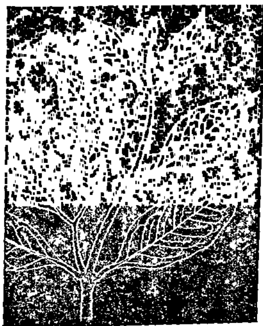
Among the gymnosperms Gnetales have reached the summit of development (evolution) and bear a close resemblance with the angiosperms. Gnetales, however, cannot be regarded as the ancestor of the angiosperms. The living Gnetales are so much advanced and so highly specialized and the fossil forms so few that their origin from any particular group of gymnosperms cannot be traced. They may have originated from an extinct group of gymnosperms—the Cordaites, and have followed a parallel line of evolution with the angiosperms. The order Gnetales are represented by one family with three genera—*Ephedra* with 35 species, *Welwitschia* with 1 species and *Gnetum* with 35 species, altogether 71 species.

GNETUM (35 sp.)

Gymnospermic Characters of *Gnetum*. (1) Ovules are naked, i.e. not enclosed within the ovary. (2) In pollination the wind-borne pollen grains are lodged directly on *the ovule, there being no style, stigma or ovary.* (3) Male and female strobili are of gymnospermic types although the flowers are more advanced with the development of the perianth. (4) The generative cell divides and produces a stalk cell and a body cell, the latter forming two male gametes. (5) Anatomically there is preponderance of gymnospermic tracheids with bordered pits. (6) Vascular bundles are in successive concentric rings, as in some cycads.

Resemblances with Angiosperms. *Gnetum* resembles angiosperms in many features—vegetative, anatomical and reproductive. (1) *Gnetum* bears well-developed broad evergreen leaves with distinct reticulate venation, hardly distinguishable from those of angiosperms (fig. 725). (2) The general climbing habit of *Gnetum* is more angiospermic than gymnospermic. (3) The presence of true vessels (of angiospermic type) in the secondary wood in addition to the tracheids (of gymnospermic type). (4) The presence of a perianth in both the male and the female flowers. (5) There are two integuments surrounding the ovule. (6) Archegonia are altogether wanting, as in all angiosperms. (7) The female gametophyte with many free nuclei has a close resemblance with the embryo sac of an angiosperm. (8) The stamen (microsporophyll) with a stalk (filament) and 1 or 2 anthers resembles that of an angiosperm. (9) The male gametophyte produces no prothallus cells, as in all angiosperms. (10) The endosperm is formed after fertilization.

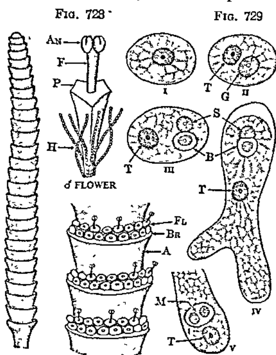
Life-history. *Gnetum* is found only in the tropics with 2 common species in India, e.g. *G. montanum* and *G. gnemon*



Gnetum. FIG. 725 A branch with leaves (reticulate venation).

both being widespread in Assam. The species of *Gnetum* are

mostly woody climbers (e.g. *G. montanum*) or shrubs or small trees (e.g. *G. gnemon*). Leaves are simple, decussate, broad, evergreen, leathery, lanceolate-ovate and distinctly net-veined (suggestive of dicotyledons). The primary stem often produces two kinds of shoots—the long shoot and the short, the latter bearing one to a few pairs of leaves. Anatomically the primary vascular bundles are formed in a ring, and the secondary vascular bundles are formed in successive concentric rings by successive cortical cambia, the primary cambium being short-lived. The secondary xylem is made of true vessels (as in angiosperms) associated with gymnospermic tracheids with bordered pits. The peculiarity with the phloem is that the



Gnetum. Fig. 726 A male strobilus. Fig. 727. A portion of the male strobilus (magnified) showing whorls of male flowers (Fl) in the axils of cup-shaped bracts (Br): A, axis. Fig. 728, A male flower; An, anther; F, filament; P, perianth; H, jointed hairs. Fig. 729. Microspore (pollen grain) and stages in the development of the male gametophyte (I-V); T, tube nucleus; G, generative nucleus; S, stalk nucleus; B, body nucleus; M, male gametes.

sieve-tube and the companion cell are formed from two separate cells (and not by the division of a single cell, as in angiosperms). Resin-ducts are absent unlike other gymnosperms.

Species of *Gnetum* are dioecious, one plant bearing male inflorescences (strobili) and another female strobili. The strobili are commonly branched, pendulous and catkin-like, bearing numerous male or female flowers, as the case may be. The strobili are commonly axillary, sometimes terminal, and grow to a length of one to a few inches.

Male Strobilus. The male strobilus (fig. 726-7) is a slender axis growing between two bracts at the base, and then at short intervals pairs of bracts, fused at an early stage into a cup-shaped structure, appear. In the axils of this cup numerous minute male flowers develop in 2-5 whorls round the axis. There may be a whorl of sterile female flowers (ovules) interposed between the whorls of male flowers. Each male flower (fig. 728) consists of a sheathing perianth (two segments fused into a tube), often surrounded at the base by jointed hairs, and a single stamen or microsporophyll. The latter consists of a stalk (filament) and two unilocular anthers containing pollen grains or microspores. Each anther opens by a terminal slit. The presence of the perianth is an angiospermic character.

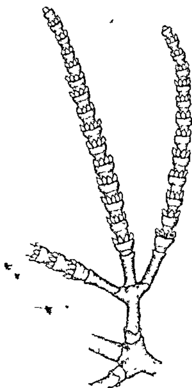




Fig. 730 Fig. 731

Gnetum. Fig. 730. A female strobilus. Fig. 731. A portion of the same (magnified) showing whorls of female flowers (F) in the axils of cup-shaped bracts (B); A, axis. Fig. 732. A female flower (ovule) magnified.

Female Strobilus (figs. 730-1). This is also a slender axis, branched or unbranched, growing between two bracts at the base. The female flowers, each represented by a single ovule, are arranged in successive

whorls round the axis in the axils of connate cup-shaped bracts (two bracts fused early into a cup). There are 4-10 female flowers or ovules in each whorl. Each ovule (fig. 732) is surrounded by a fleshy perianth (two outgrowths appearing from the base of the ovule get fused at a very early stage) forming the outer covering. The perianth finally turns orange-red in colour in the seed. The ovule (fig. 733) consists of two envelopes or integuments and a distinct nucellus or megasporangium, and is orthotropous in nature. Of the two integuments the outer one is stony and the inner one is projected beyond the perianth into a sort of style or micropylar tube with its tip lobed or fimbriated. The embryo-sac or megaspore lies embedded in the nucellus towards the chalazal end. Beneath this a fan-shaped nutritive tissue, called the *pavement tissue*, formed of radiating rows of cells, develops in the nucellus. It, however, gets disorganized after fertilization.

Male Gametophyte (fig. 729). Pollen grains often germinate while still in the micropylar chamber. Some of them, however, directly reach the nucellus and germinate there. The pollen grain on germination gives rise to a very simple type of male gametophyte without any prothallus cell, as in angiosperms. The nucleus of the pollen grain or microspore [I] divides at first into two nuclei, one of which is the vegetative or **tube nucleus** and the other the antheridial or **generative nucleus** [II]. The latter divides further into a **stalk nucleus** and a **body nucleus** [III]. The body nucleus organizes itself into a cell with a cell-wall. The exine of the pollen grain falls off and the intine grows into the pollen-tube [IV]. The body cell and the tube nucleus (but not the stalk nucleus) move forward into the pollen-tube. The body cell again divides and produces two **male gametes** which migrate to the tip of the pollen-tube [V].

Female Gametophyte (fig. 734). The megaspore mother-cell divides and produces four megaspores, one or more of which may be functional. The megaspore germinates with repeated free nuclear divisions and gives rise to the embryo-sac or female gametophyte which lies deep-seated in the nucellus. One or more of the free nuclei, particularly at the micropylar end, may be organized with a mass of protoplasm around them into potential egg-nuclei, and may be fertilized. No archegonium is formed in *Gnetum*, as in angiosperms. In some species, as in *G. gnemon*, a multinucleate (later uninucleate) cellular tissue (prothallial tissue), interpreted as homologous with the antipodal cells of angiosperms, is formed at the basal part of the female gametophyte (fig. 735); after

fertilization it fills up the whole of the gametophyte. In gymnosperms the prothallial tissue is designated as the endo-

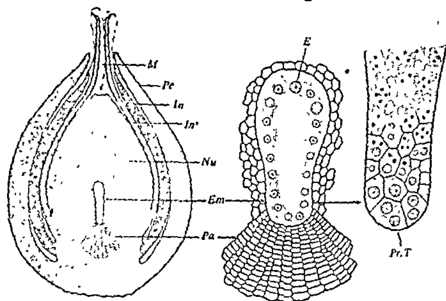


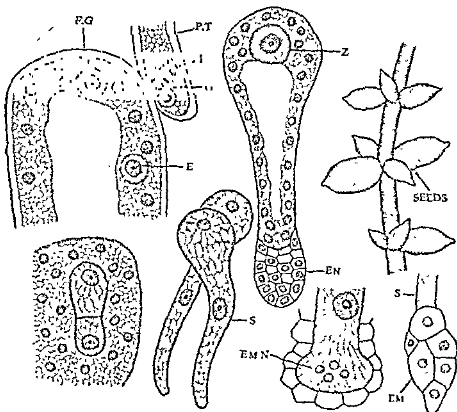
Fig. 733 Fig. 734 Fig 735

Gnetum. Fig 733 Ovule in longitudinal section showing micropylar tube (M), perianth (Pe), outer integument (In), inner integument (In'), nucellus (Nu), embryo-sac or female gametophyte (Em) and pavement tissue (Pa). Fig 734. Female gametophyte (magnified) showing many free nuclei, a few eggs (E) and pavement tissue (Pa) beneath. Fig 735 Development of prothallial tissue (*Pr.*T) at the base of the female gametophyte.

sperm. It is noticeable that the female gametophyte of *Gnetum* with many free nuclei and without any trace of archegonium has almost reached the angiosperm level.

Fertilization and Development of the Embryo. One or more pollen-tubes penetrate through the micropylar chamber and the nucellus. Finally the tubes reach the female gametophyte (fig. 736) and enter into it. The male gametes are discharged through a terminal pore in the pollen-tube. Both the male gametes are functional, and fertilization takes place by the fusion of any of them with any free egg-nucleus. Each fertilized egg-nucleus clothes itself with a wall and becomes the *oospore* (fig. 737). Some of the unfertilized nuclei divide and form a prothallial tissue (endosperm), while others get disorganized. The endosperm grows quickly and soon invades the whole of the nucellus space. In *Gnetum* most of the endosperm tissue is formed after fertilization. Many oospores or even embryos may be formed but ultimately one embryo comes to maturity. In the formation of the embryo the oospore divides and forms at first a two-celled **pro-embryo** (fig.

738). Each cell of the pro-embryo grows into a long slender tubular **suspensor** (fig. 739). The nucleus of it divides into two; one of these two undergoes free nuclear divisions forming



Gnetum. Fig 736. Pre-fertilization stage: female gametophyte (F.G) and pollen-tube (P T); E, egg nucleus; T, tube-nucleus; G, male gametes. Fig. 737. Female gametophyte after fertilization showing zygote (Z), free nuclei, and development of endosperm (EN). Fig. 738. Pro-embryo. Fig. 739. Two suspensors (S) developing from the 2-celled pro-embryo. Fig. 740. End of a suspensor showing four embryonal nuclei (EM.N). *Fig. 741. Embryo (EM) and suspensor (S). Fig. 742. Female strobilus* with groups of seeds.

four free nuclei at the end of the suspensor (fig. 740), while the other nucleus does not divide. These four free nuclei organize themselves and give rise to the embryo (fig. 741). Further details of embryo-development in *Gnetum* are not, however, known. Although there are many ovules, not many seeds are formed. The seed (*fig. 742) is albuminous, the perianth fleshy* and orange-red in colour, and the embryo is with two cotyledons (dicotyledonous type).

PART VII

ANGIOSPERMS

CHAPTER I

LIFE-HISTORY OF AN ANGIOSPERM

Life-history. *Life-history* of a plant comprises all the stages starting from any particular stage, and finally reaching the same stage again; it is a circuitous journey passing through successive developmental stages. Life-history is, therefore, its life-cycle without any beginning or end. In the *life-cycle of an angiosperm* there are certain special features, as compared with cryptogams. Development of the pollen-tube, the seed and the $3n$ endosperm, absence of antheridia and archegonia, double *fertilization*, complexity of the sporophyte and extreme reduction and *loss of independence of the gametophyte* are some such features.

Starting from the stage of a plant with roots, stem, leaves and flowers we may *follow the successive* stages in its life-cycle. *The flower* bears stamen or microsporophyll and carpel or megasporophyll. The stamen bears pollen sac or microsporangium and the carpel bears nucellus or megasporangium within the ovule which again develops within the ovary. The

the female gametophyte bears
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As a result of this *double*
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(oospore) which *quickly grows into*
two *polar nuclei* and one *male gamete*)
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Alternation of Generations. *In angiosperms* the sporophyte has reached a high degree of complexity, while the gametophytes have become very *small* simple and inconspicuous. The angiospermic plant is *the sporophyte* with $2n$ or *diploid* chromosomes. The embryo-sac with the eight *nuclei* and the germinating pollen grain including the pollen-tube with the *three* nuclei are the *female* and the male gametophytes respectively with n or *haploid* chromosomes. The endosperm *with $3n$ chromosomes* formed as a result of

triple fusion is a unique structure in the angiosperm. All the stages from the zygote to the spore mother-cells (mega- and micro-) represent the sporophytic generation, and all the stages from the spores (mega- and micro-)

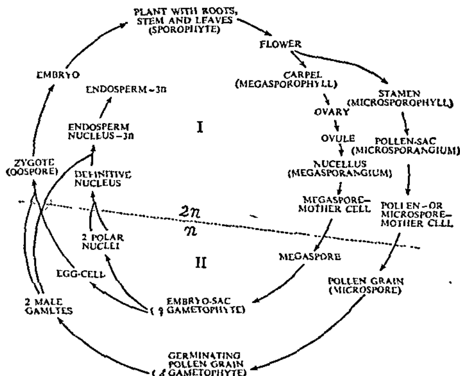


FIG. 743. Life history of an angiosperm. I, sporophytic or diploid (2n) generation; II, gametophytic or haploid (n) generation.

to the gametes (male and female) represent the gametophytic generation. These two generations (sporophytic and gametophytic) regularly alternate with each other to complete the life-cycle of an angiosperm.

CHAPTER II

PRINCIPLES AND SYSTEMS OF CLASSIFICATION

Systematic Botany or Taxonomy. It deals with the description, identification and naming of plants, and their classification into different groups according to their resemblances and differences mainly in their morphological characteristics. So far as angiosperms or higher 'flowering' plants are concerned it has been estimated that over 199,000 species (dicotyledons—159,000 and monocotyledons—40,000) are already known to us, and that many thousands more have yet to be discovered and recorded. Thus plants are not only numerous but they are of varied types, and it is not possible to study them unless they are arranged in some orderly system. The object of systematic botany or taxonomy is to describe, name and classify

plants in such a manner that their relationship with regard to their descent from a common ancestry may be easily brought out. The ultimate object of classification is to arrange plants in such a way as to give us an idea about the sequence of their evolution from simpler, earlier and more primitive types to more complex, more recent and more advanced types in different periods of the earth. The earlier classifications of plants were based on their economic uses, e.g. cereals, medicinal plants, fibre-yielding plants, oil-yielding plants, etc., or on gross structural resemblances, e.g. herbs, shrubs, climbers, etc. These classifications were incomplete and fragmentary as plants that did not fit into the classifications or were of no economic value were usually ignored. An ideal system of classification should, therefore, not only indicate the actual genetic relationship but should also be within a reasonable limit of convenience for practical purposes.

UNITS OF CLASSIFICATION

Species. By the term species we mean a collection of individuals (plants) which resemble one another in almost all important morphological characters—both vegetative and reproductive, so closely that they may be regarded as having been derived from the same parents. Take pea, for instance. The individuals in a field may differ from one another in the size of the plant or the shape of the fruit or in some minor characters, but they show a remarkable resemblance among themselves as regards the general appearance, and the structure of leaves, flowers, fruits and seeds. The resemblance among the individuals is so close that all pea plants may be regarded as having been derived from the same parents. Thus all pea plants constitute a species. Similarly all banyan plants, all peepul plants, and all mango plants constitute different and distinct species.

Occasionally due to variations in climatic or edaphic conditions individuals of a species may show certain amount of variations in form, size, colour and other minor characteristics. Such plants are said to form **varieties.** A species may consist of one or more varieties or none at all. We have thus different varieties of common garden pea, rice, mango, etc. Varieties, however, are not permanent. They tend to revert to the original species from which they were derived.

Genus. A genus is a collection of species which bear a close resemblance to one another in the morphological characters of the floral or reproductive parts. For example, banyan, peepul and fig are different species because they

class has been divided by Bentham and Hooker into eight series.

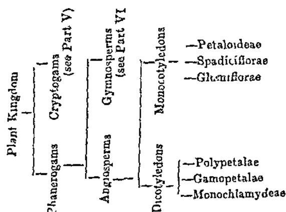
According to Bentham and Hooker the monocotyledons are divided into seven series. They start with families having epigynous flowers, as in *Orchidaceae* (orchid family) and *Scitamineae* (banana family), pass through families with petaloid hypogynous flowers, as in *Liliaceae* (lily family), and then through families with flowers which have lost their petaloid character, as in *Palmaceae* and *Araceae* and ultimately to *Graminaceae* and *Cyperaceae* with the simple construction of the flower and the presence of glumes. A much simpler classification has been put forward by Vines in England. According to this author the monocotyledons are divided into three *sub-classes*, as follows:

1. **Petaloideae.** The perianth is usually petaloid.

2. **Spadiciflorae.** The inflorescence is a spadix, and it is enclosed in one or more spathes.

3. **Glumiflorae.** The flower is enclosed in special bracts, called *glumes* (see p. 110).

An outline of the above system of classification is given in the following schedule up to sub-classes:



Following the above scheme of classification any plant may be referred to its systematic position. Let us take BANI cotton.

Division	...	...	... Phanerogam
Sub-division	...	...	... Angiosperm
Class	...	...	... Dicotyledon
Sub-class	...	...	... Polypetalae
Series	...	...	... Thalamiflorae
Order	...	...	... Malvales
Family	...	...	... *Malvaceae*
Genus	...	...	... *Gossypium*
Species	...	...	... *indicum*

A plant is always denominated by the *generic* and *specific* name, with the name of the author at the end. Thus BANI cotton is *Gossypium indicum* Linn.

[illegible] (1892). The principle involved in this [illegible] increasing complexity of flowers, parti- [illegible] *ding to this system in the earliest types* [illegible] only one whorl, and in the higher types [illegible] come again two stages in the develop- [illegible] the lower, the members of each whorl [illegible] the higher, there is distinction in form and colour *between the two whorls, called calyx and corolla* According to this system gamopetalous condition (sub-class Sympetalae) represents a more advanced stage than the polypetalous condition. Within the sub-class progress is indicated through hypogyny, perigyny and epigyny, and from an indefinite number of stamens and carpels to a definite number The lower orders of dicotyledons *come under the sub class Archichlamydeae* and the higher orders under the sub-class Sympetalae In this system monocotyledons take precedence of dicotyledons Monocotyledons have been classified into 11 orders and 45 families, and dicotyledons into 40 orders and 241 families

Dicotyledons and Monocotyledons. The division of angiosperms into the two great classes is based on the following characters:

1. In dicotyledons the embryo bears *two cotyledons;* whereas in monocotyledons it bears *only one*.

2. In the dicotyledonous embryo the plumule is *terminal* and the two cotyledons *lateral;* but in the monocotyledonous embryo the plumule is *lateral* and the cotyledon *terminal.* This *is, however, not true in all cases.*

3. In dicotyledons the primary root persists and gives rise to the *tap root;* while in monocotyledons the primary root soon perishes and is replaced by a cluster of *adventitious (fibrous) roots.*

4. As a rule venation is *reticulate* in dicotyledons and *parallel* in monocotyledons. Among monocotyledons aroids, sarsaparilla (*Smilax*) and yams (*Dioscorea*), however, show reticulate venation (see figs. 117-8), and among dicotyledons Alexandrian laurel (*Calophyllum*) shows parallel venation (see fig. 119).

5. The dicotyledonous flower has commonly a *pentamerous* symmetry; while the *monocotyledonous* one a *trimerous* symmetry.

6. In the dicotyledonous stem the vascular bundles are *arranged in a ring* and they are *collateral* and *open*, that is, they contain a strip of cambium which *gives rise to the secondary* growth; while in the monocotyledonous stem the bundles are *scattered* in the ground tissue and they are *collateral* and

closed, that is, they do not contain any cambium (with but few exceptions), and hence there is no secondary growth. Also the bundles are more numerous in monocotyledons than in dicotyledons. Further, the bundles are more or less oval in monocotyledons and wedge-shaped in dicotyledons.

7. In the dicotyledonous root the number of xylem bundles varies from *2 to 6*, seldom more, but in the monocotyledonous root these are *numerous*, seldom a limited number (5 to 8).

Cambium soon makes its appearance in the dicotyledonous root as a secondary meristem and gives rise to the secondary growth, but in the monocotyledonous root cambium is absent (leaving out the exceptions) and hence there is no secondary growth.

Floral Diagram. The number of parts of a flower, their general structure, *arrangement and the relation they bear to* one another (aestivation) may be represented by a diagram known as the **floral diagram.** The floral diagram is the ground plan of a flower. In the diagram the calyx lies outermost, the corolla internal to the calyx, the androecium in the middle, and the gynoecium in the centre. Adhesion and cohesion of members of different whorls may also be shown clearly by connecting the respective parts with lines; as, for example,

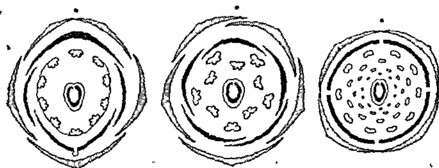


FIG. 746 FIG. 744 FIG. 745

Floral Diagrams (three types). Fig. 744. *Papilionaceae.* Fig. 745. *Caesalpinieae.* Fig. 746. *Mimoseae.*

fig. 744 shows that there are altogether ten stamens, of which nine are united into one bundle and the remaining one is free. The black dot on the top represents the position of the mother axis (not the pedicel) which bears the flower. The axis lies behind the flower and, therefore, the side of the flower nearest to the axis is called the *posterior* side, and the other side away from the axis the *anterior* side. The charac-

ters of a family or a genus may be represented by one or more diagrams.

A particular species or sometimes a particular genus may be well represented by a single diagram. But to represent a family, particularly with varying characters, more diagrams than one often become necessary. In the following pages the diagrams that are given represent only particular types.

Floral Formula. The different whorls of a flower, their number, cohesion and adhesion may be represented by a formula known as the **floral formula.** In the floral formula *K* stands for calyx, *C* for corolla, *P* for perianth, *A* for androecium and *G* for gynoecium. The figures following the letters *K, C, P, A* and *G* indicate the number of parts of those whorls. Cohesion of a whorl is shown by enclosing the figure within brackets, and the adhesion is shown by a line drawn on the top of the two whorls concerned. In the case of the gynoecium the position of the ovary is shown by a line drawn above or below *G* or the figure. If the ovary is superior the line should be below it, and if it is inferior the line should be on the top. Thus all the parts of a flower are represented in a general way by the floral formula ; the floral characters of a family may also be represented by one or more formulae, as follows:

Ranunculaceae—$K_{3-\infty}\ C_{5-\infty}\ A_{\infty}\ \underline{G}_{\infty}$

Annonaceae —$K_3\ C_{3+3}\ A_{\infty}\ \underline{G}_{\infty}$

Nymphaeaceae—$K_4\ C_{\infty}\ A_{\infty}\ \underline{G}_{(\infty)\text{ or }\infty}$

Cruciferae —$K_{2+2}\ C_4\ A_{2+4}\ \underline{G}_{(2)}$

Malvaceae —$K_5\ \overline{C_5\ A_{(\infty)}}\ \underline{G}_{(5-\infty)}$

Cucurbitaceae— ♂ $K_{(5)}\ C_{(5)}\ A_{3\text{ or }5}$

♀ $K_{(5)}\ C_{(5)}\ \overline{G}_{(3)}$

Apocynaceae—$K_{(5)}\ \overline{C_{(5)}\ A_5}\ \underline{G}_{(2)\text{ or}}$

Solanaceae —$K_{(5)}\ \overline{C_{(5)}\ A_5}\ \underline{G}_{(2)}$

Labiatae —$K_{(5)}\ \overline{C_{(2+3)}\ A_{2+2}}\ \underline{G}$

Features used to describe an Angiospermic Plant

Habitat: natural abode of the plant.

Habit: herb (erect, prostrate, decumbent, diffuse, trailing, twining or climbing), shrub (erect, straggling, twining or climbing) or tree or any other peculiarity in the habit.

Root: nature of the root; any special form.

Stem: kind of stem—herbaceous or woody; cylindrical or angular; hairy or smooth; jointed or not; hollow or solid; erect, prostrate, twining or climbing; nature of modification, if any.

Leaf: arrangement—whether alternate, opposite (superposed or decussate) or whorled; stipulate or exstipulate; nature of the stipules, if present, simple or compound; nature of the compound leaf and the number of leaflets; shape and size; hairy or smooth; deciduous or persistent; venation; margin; apex; and petiole.

Inflorescence: type of inflorescence (to be explained).

Flower: sessile or stalked; complete or incomplete; unisexual or bisexual; regular, zygomorphic, or irregular; hypogynous, epigynous or perigynous; bracteate or ebracteate; nature of bracts and bracteoles, if present; shape of the flower, its colour and size.

Calyx: *polysepalous or gamosepalous*; number of sepals or of lobes; superior or inferior; aestivation; shape, size and colour.

Corolla: polypetalous or gamopetalous; number of petals or of lobes; superior or inferior, aestivation; shape, size, colour and scent; corona or any special feature

(When there is not much difference between the calyx and the corolla the term perianth should be used; it may be sepaloid or petaloid; polyphyllous or gamophyllous.)

Androecium: number of stamens—definite (ten or less) or indefinite (more than ten) free or united; nature of cohesion—monadelphous, diadelphous, polyadelphous, syngenesious or synandrous; nature of adhesion—epipetalous or gynandrous, or any special feature; whether alternating with the petals (or corolla lobes) or opposite them. Length of stamens—general length, inserted or exerted, didynamous or tetradynamous; position of stamens—hypogynous, perigynous or epigynous; attachment of the anther and its dehiscence, anther-lobes or appendages, if any.

Gynoecium or Pistil: number of carpels; syncarpous or apocarpous; nature of style—long or short; stigmas—simple, lobed or branched, their number and nature—smooth or papillose; ovary—superior or inferior; number of lobes, number of chambers (loculi), nature of placentation; number and form of ovules in each loculus of the ovary.

Fruit: kind of fruit (to be explained).

Seeds: number of seeds in the fruit; shape and size; albuminous or exalbuminous, nature of albumen, if present.

CHAPTER III

SELECTED FAMILIES OF DICOTYLEDONS

SUB-CLASS I. POLYPETALAE

Family 1—*Ranunculaceae* (1,200 sp.—163 sp. in India)

Habit—annual or perennial herbs or climbing shrubs, usually with an acrid juice. **Leaves** simple or compound, alternate or rarely opposite, radical and cauline, usually with sheathing base. **Inflorescence** racemose or cymose. **Flowers** mostly regular (actinomorphic), sometimes zygomorphic, as in larkspur and monk's hood, bisexual and *hypogynous*; *floral members* typically spiral on the elongated thalamus, or in whorls. **Calyx**—sepals 3-∞, usually 5, free, sometimes brightly coloured. **Corolla**—petals 5 or more, free, sometimes absent, often with nectaries, imbricate; perianth leaves (when calyx and corolla not distinguishable) free and petaloid. **Androecium**—stamens

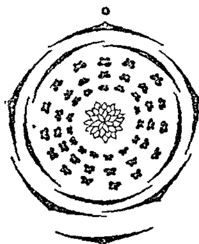
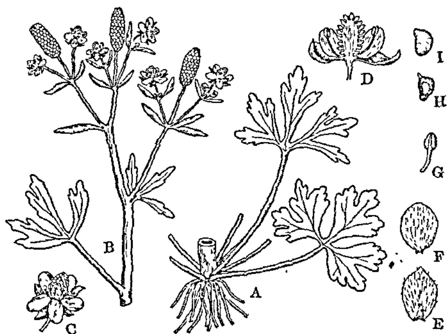


FIG. 747. Floral diagram of *Ranunculaceae*.

numerous, free, usually spiral. **Gynoecium**—carpels usually numerous, sometimes few—3-7, free (apocarpous), usually spiral, with one to many ovules in each, in *Nigella* carpels are united at the base. **Fruit** an etaerio of achenes or follicles, rarely a berry or capsule. **Seeds** albuminous. *Floral formula*—$K_{3-\infty} C_{5-\infty} A_{\infty} \underline{G}_{\infty}$.

Examples. **Useful plants**—monk's hood or aconite (*Aconitum ferox*; B. KATBISH, H. BISH, P. MITHA-TELIA)—medicinal, tuberous roots containing a very poisonous alkaloid, devil-in-a-bush (*Nigella sativa*; B & H. KALA-JIRA; P. KALONGI)—seeds used as a condiment; **ornamental:** larkspur (*Delphinium*; see fig. 234), wind flower (*Anemone*)—a small tuberous plant with woolly achenes for wind-dispersal, virgin's bower (*Clematis*—see figs. 62 and 339)—a climbing shrub, columbine (*Aquilegia*), buttercup (*Ranunculus*), etc.

Other common plants of the family—*Ranunculus* (300 sp.—a few sp in India), e.g Indian buttercup (*Ranunculus sceleratus*) usually growing in river- and marsh-banks, water crowfoot (*R.*



Ranunculaceae. FIG. 748. *Ranunculus sceleratus*. *A*, basal portion of the plant with leaves and roots; *B*, upper portion of the same with inflorescence; *C*, a flower; *D*, flower cut longitudinally; *E*, a sepal; *F*, a petal; *G*, a stamen; *H*, a carpel; and *I*, a fruit (achene).

aquatilis) growing in water and showing heterophylly (see p. 90), traveller's joy (*Naravelia*; B. CHHAGALBATI—see figs. 147 and

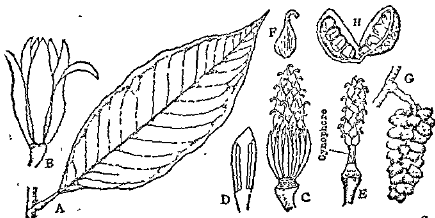
340)—a climbing shrub, *Thalictrum* (H. PINJARI)—a perennial herb, etc.

Description of *Ranunculus sceleratus* (fig. 748). An annual weed, 2 ft. or more in height, growing usually on the banks of rivers and marshes. **Leaves** simple—radical leaves being tri-partite and cauline leaves being tri-fid. **Flowers** regular, bisexual, hypogynous, yellow, each borne at the end of a branch. **Calyx**—sepals 3-5, imbricate, caducous, hairy. **Corolla**—petals 5, free, yellow, alternating with the sepals, each with a nectary. **Androecium**—stamens numerous, free, spirally arranged; filament flattened below: anther basifixed. **Gynoecium**—carpels numerous, free, each with one ovule; style very short and curved. **Fruit** an etaerio of beaked achenes. **Seeds** albuminous.

Family 2—*Magnoliaceae* (300 sp.—36 sp. in India)

Habit—shrubs and trees. **Leaves** simple, alternate, often with large stipules covering young leaves. **Flowers** solitary, terminal or axillary, often large and showy, aromatic; they are regular, bisexual, and hypogynous. **Perianth** leaves all alike, petaloid, deciduous; either cyclic being arranged in whorls of 3 (trimerous) or acyclic (spiral); sometimes the outer whorl sepaloid. **Androecium**—stamens numerous, free; filament short or absent; anther-lobes linear, 4; with prolonged connective. **Gynoecium**—carpels numerous, free, arranged spirally round the elongated thalamus; ovules 1 or few in each carpel. **Fruit** an aggregate of berries or follicles. **Seed** albuminous. Endosperm of the seed non-ruminated. *Floral formula*—$P_{\infty}\, A_{\infty}\, \underline{G}_{\infty}$.

Examples. Mostly ornamental evergreen plants with fragrant flowers—*Michelia champaca* (B. CHAMPA; H. CHAMPAK), *M. alba* (B. CHINA-CHAMPA), *Magnolia grandiflora* (B. DULEE-CHAMPA) *M. pumila* (=*Talauma pumila*; B. JAHURE-CHAMPA) and *M. fuscata* (B. CHINI-CHAMPA).

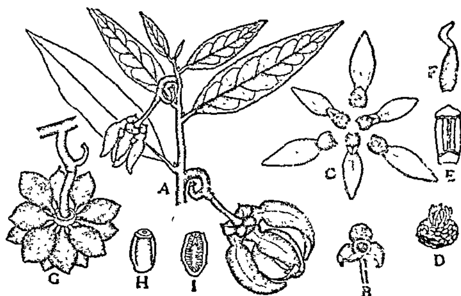


Magnoliaceae. FIG. 749. *Michelia champaca*. *A*, a leaf; *B*, a flower; *C*, stamens and carpels spirally arranged on the thalamus; *D*, a stamen with four anther-lobes; *E*, carpels (*free*); *F*, a carpel; *G*, aggregate fruits (follicles); and *H*, a follicle dehiscing.

Family 3—*Annonaceae* (820 sp.—129 sp. in India)

Habit—shrubs and trees, sometimes climbers. **Leaves** simple, alternate, distichous and exstipulate. **Flowers** regular, bisexual, and hypogynous; often aromatic. **Perianth** usually in three whorls of three members each; sepals 3 and petals 6 in two whorls. **Androecium**—stamens numerous, free, arranged spirally round the slightly elongated thalamus; filament short or absent; anther-lobes linear, 4; with prolonged connective. **Gynoecium**—carpels numerous, free or connate; ovules one to many in each carpel. **Fruit** an aggregate of berries. **Seed** with the endosperm distinctly ruminated, i.e. marked by irregular wavy lines. *Floral formula*—$K_3\ C_{3+3}\ A_{\infty}\ \underline{G}_{\infty}$.

Examples. Custard-apple (*Annona squamosa*; B. ATA; H. & P. SHARIFA or SITAPHAL)—fruit edible, bullock's heart (*A. reticulata*; B. NONA; H. RAMPHAL)—fruit edible, sour sop (*A. muricata*)—fruit edible, *Artabotrys odoratissimus* (B. & H. KANTALI-CHAMPA)—flowers fragrant, *Unona discolor* (B. LAVENDAR-CHAMPA)—flowers with very fragrant odour, mast tree (*Polyalthia*; B. DEBDARU; H. DEVADARU or ASHOK)—evergreen tall tree, leaves used for decoration, *Uvaria macrophylla*—a



Annonaceae. FIG. 750. *Artabotrys*. *A*, a branch with two flowers; *B*, calyx; *C*, petals spread out; *D*, stamens and carpels; *E*, a stamen with four anther-lobes; *F*, a carpel; *G*, an aggregate of berries; *H*, a seed; and *I*, the seed cut longitudinally showing the ruminated endosperm.

climber, and *Cananga odorata*—flowers yield Macassar oil There is a large number of wild species of *Annonaceae*.

Family 4—*Nymphaeaceae* (100 sp.—11 sp. in India)

Habit—aquatic perennial herbs. **Leaves** usually floating, borne on a long petiole, cordate or peltate. **Flowers** often large, *showy, solitary*, on a long pedicel, usually *floating*; bisexual, regular and usually perigynous, sometimes hypogynous or even

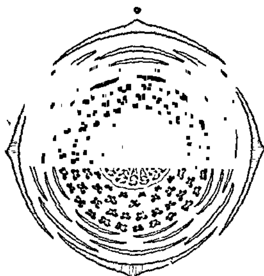


FIG. 751. Floral diagram of *Nymphaeaceae*.

epigynous; thalamus fleshy and goblet-shaped. **Perianth** leaves several, free; sepals usually 4, gradually merging into petals; petals numerous, gradually merging into stamens. **Androecium**—stamens numerous, free, usually perigynous, adnate to the fleshy thalamus that envelops the carpels. **Gynoecium**—carpels several, either free on the fleshy thalamus, as in lotus, or syncarpous lying embedded in the thalamus and surrounded by it; ovary unilocular with one ovule or multilocular with many ovules on superficial placentation; stigmas sessile, free or united, radiating, often with horn-like appendages. **Fruit** a berry. **Seeds** solitary and exalbuminous, or many with both perisperm and endosperm; spongy aril is often present and helps the seed to float. *Floral formula*—$K_4 C_\infty A_\infty \underline{G}_{(\infty) \text{ or } \infty}$.

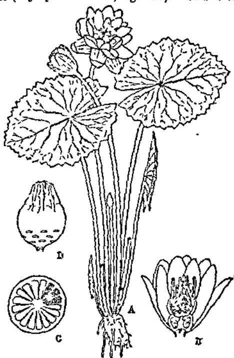
Examples. Plants often cultivated for pond decoration—water lilies such as *Nymphaea lotus* (B. SHALOOK; H. & P. NILOFAR), *N. rubra* (B. RAKTO-KAMBAL), *N. stellata* (B. & H. NIL-



FIG. 752. Giant water lily (*Victoria regia*) Photograph taken at the Indian Botanic Garden, Calcutta.

PADMA), *Euryale ferox* (B. & H. MAKHNA), lotus (*Nelumbium speciosum* ; B. PADMA ; H. & P. KANWAL)—rhizome eaten, and giant water lily (*Victoria regia*—it bears huge tray-like leaves. each measuring six feet or more in diameter; although a native of South America this plant may be seen in luxuriant growth about October in the Indian Botanic Garden near Calcutta). Lotus has some distinctive characters of its own: (1) leaves and flowers are raised above the surface of water · (2) flowers hypogynous ; (3) carpels several, free (apocarpous). and embedded in the upper surface of the top-shaped thalamus ; (4) ovary unilocular with one ovule ; (5) stigmas sessile, solitary : and (6) seeds exalbuminous.

Description of Water Lily Plant (*Nymphaea lotus*; fig. 753). This is an aquatic perennial herb growing in shallow water; it is provided with creeping rootstock **Leaves** floating, radical, on long petioles, involute; stomata on the upper side. **Flowers** floating on long scapes; bisexual, acyclic; sepals, petals and stamens half superior, inserted on the disk which is confluent with the carpels **Calyx**—sepals 4, free, adnate to the base of the disk, gradually merging into petals. **Corolla**—petals many, free, adnate to the disk, arranged spirally and gradually merging into stamens. **Androecium**—stamens numerous, perigynous, outer filaments petaloid; anthers erect, linear, with appendages, dehiscence introrse. **Gynoecium**—carpels many in one whorl; ovary many-celled, semi-inferior; stigmas sessile, radiating and furrowed, with horn-like appendages; placentation superficial; ovules numerous, anatropous. **Fruit** a spongy berry ripening under water. **Seeds** numerous, very small, enveloped in a spongy saccate aril which encloses air-bubbles; perisperm present round the endosperm.



Nymphaeaceae FIG 753. Water lily (*Nymphaea lotus*). *A*, an entire plant; *B*, a flower cut longitudinally (see also figs. 217-8; *C*, transverse section of the ovary; and *D*, a young fruit.

Family 5—*Cruciferae* (2,000 sp.—178 sp. in India)

Habit—herbs. **Leaves** radical and cauline, simple, alternate, often lobed, or sometimes pinnately compound. **Inflorescence** a raceme. **Flowers** regular and cruciform, bisexual and complete, hypogynous. **Calyx**—sepals 2+2, free, in two whorls. **Corolla**—petals 4, free, in one whorl, cruciform, with distinct limb and claw. **Androecium**—stamens 6, in two whorls, 2 outer short and 4 inner long (tetradynamous). **Gynoecium**—carpels (2), syncarpous; ovary superior; at first 1-celled, but subsequently becoming 2-celled owing to the development of a false septum, called the *replum*, with often many ovules in each cell, sometimes only 2; pla-

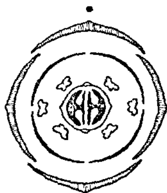
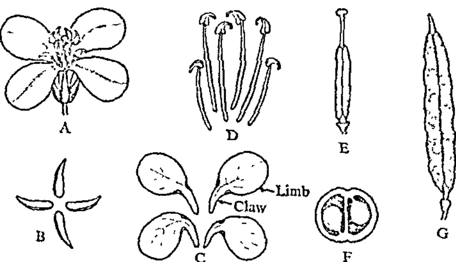


FIG. 754. Floral diagram of *Cruciferae*.

centation parietal. **Fruit** a siliqua. **Seeds** exalbuminous. *Floral formula*—$K_{2+2}\ C_4\ A_{2+4}\ \underline{G}_{(2)}$.

Examples. **Useful plants—oils and condiments:** mustard (*Brassica campestris*; B. SHARISHA; H. & P. SARSON), Indian mustard (*B. juncea*; B. RAI-SHARISHA; H. RAI), Indian rape



Cruciferae. FIG. 755. Mustard (*Brassica campestris*) flower. *A*, a flower —cruciform; *B*, calyx; *C*, corolla opened out; *D*, androecium showing tetradynamous stamens; *E*, gynoecium showing two carpels united; *F*, ovary in transection showing parietal placentation and replum; and *G*, a fruit—siliqua. [See also fig. 1].

(*B. napus*; B. RAI; H. TORIO), white mustard (*B. alba*; B. SWET-SHARISHA; H. SAFED-RAI), black mustard (*B. nigra*; B. KRISHNA-SHARISHA; H. KALI-SARSON), etc.; **vegetables**: radish (*Raphanus sativus*), cabbage (*Brassica oleracea* var. *capitata*), cauliflower (*B. oleracea* var. *botrytis*), turnip (*B. rapa*; B. SHALGAM; H. SHALJAM), kohl-rabi or knol-kohl (*B. caulorapa*), *B. rugosa* (B. LAI-SAK), garden-cress (*Lepidium sativum*; B. HALIM-SAK; H. HALIM; P. HALON), water-cress (*Nasturtium officinale*), etc.; **ornamental**: candytuft (*Iberis*; H. & P. CHANDNI), wallflower (*Cheiranthus*), alison (*Alyssum*), etc.

Other common plants of the family—*Nasturtium indicum* (B. BIL-RAI), *Eruca sativa* (B. SWET-RAI; P. TAMARIRA), bitter cress (*Cardamine hirsuta*), shepherd's purse (*Capsella bursa-pastoris*), etc.

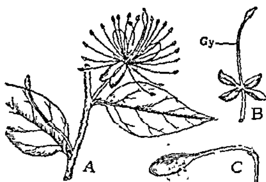
Description of Mustard Plant (*Brassica campestris*; fig. 755). **A cultivated winter herb. Leaves** simple, alternate, radical and cauline, lyrate. **Inflorescence** a raceme. **Flowers** regular, bisexual, hypogynous, cruciform.

and bright yellow in colour. **Calyx**—sepals 4, free, imbricate **Corolla**—petals 4, free, cruciform, imbricate, and with distinct claw and limb. **Androecium**—stamens 6, free, 4 inner long and 2 outer short (tetradynamous). **Gynoecium**—carpels (2), syncarpous; ovary divided into 2 chambers by the placental replum; placentation parietal. **Fruit** a narrow, pod-like siliqua opening into 2 valves from base upwards. **Seeds** many, small, globose and exalbuminous.

Family 6—*Capparidaceae* (450 sp.—165 sp. in India)

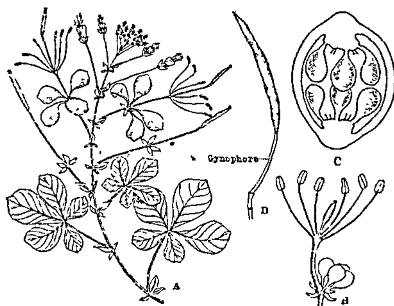
Habit—herbs, climbing shrubs, and trees. **Leaves** mostly alternate, rarely opposite, simple or palmately compound; stipules, if present, minute or spiny. **Flowers** regular (actinomorphic), sometimes zygomorphic, hypogynous or perigynous, and bisexual; thalamus in some cases elongated (gynophore) between the stamens and the pistil, sometimes both androphore and gynophore develop. **Calyx**—sepals usually 4, free. **Corolla**—petals usually 4 or varying in number, free. **Androecium**—stamens usually many, sometimes 6, free. **Gynoecium**—carpels (2) or more, syncarpous; ovary superior, 1-celled, or chambered by false partition walls, with parietal placentation; ovules usually many. **Fruit** an elongated capsule or a berry. *Floral formula*—$K_4\ C_4\ A_{\infty \text{ or } 6}\ \underline{G}_{(2-\infty)}$.

Examples, *Polanisia icosandra* (B. HALDE-HURHURE; H. HULHUL), *Gynandropsis gynandra* (B. SWET-HURHURE; H. HURHUR—fig. 757), *Capparis sepiaria* (B. KANTAGURKAMAI; H. HIUN; P. HIUS), caper (*C. horrida*; B. BAGNAI), *C. aphylla* (P. KARIR), *C. spinosa* (B. & H. KABRA) and *Crataeva religiosa* (B. BARUN; H. & P. BARNA).



Capparidaceae. FIG 756. *Capparis sepiaria* *A*, a portion of a branch; *B*, pistil seated on gynophore (*Gy*), and calyx at the base. *C*, a fruit.

Description of *Gynandropsis gynandra* (fig. 757). An erect annual weed, strongly smelling. **Leaves** alternate, palmately compound. **Inflorescence** a raceme **Flowers** regular, bisexual and hypogynous, white or purplish; thalamus elongated showing distinct androphore and gynophore. **Calyx**—sepals 4, free. **Corolla**—petals 4, free, long-clawed. **Androecium**—stamens 6, free. **Gynoecium**—carpels (2), syncarpous; ovary superior, 1-celled, on a stalk (gynophore), with parietal placentation, with many ovules. **Fruit** a linear capsule.



Capparidaceae. Fig 757. *Gynandropsis gynandra. A*, a branch with leaves and flowers; *B*, a flower, *C*, section of ovary showing parietal placentation; and *D*, a fruit.

Family 7—*Malvaceae* (1,000 sp.—111 sp. in India)

Habit—herbs, shrubs and trees. **Leaves** simple, alternate and palmately-veined; stipules 2, free lateral. **Flowers** regular, polypetalous, bisexual, hypogynous, copiously mucilaginous, with a whorl of bracteoles known as the *epicalyx*. **Calyx**—sepals (5), united. **Corolla**—petals 5, free, attached to the base of the staminal tube; aestivation twisted. **Androecium**—stamens numerous, monadelphous, i.e. united into one bundle called staminal column or tube, epipetalous (staminal tube adnate to the petals at the base); anthers unilocular. **Gynoecium**—carpels (5 to ∞), syncarpous; ovary superior, multilocular, with 1 to many ovules in each loculus; placentation axile; style passes through the staminal tube; stigmas free, as many as the carpels. **Fruit** a capsule or sometimes a schizocarp. *Floral formula*—$K_{(5)}C_5A_{(\infty)}\underline{G}_{(5-\infty)}$

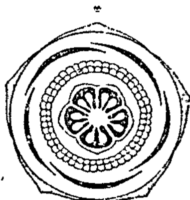
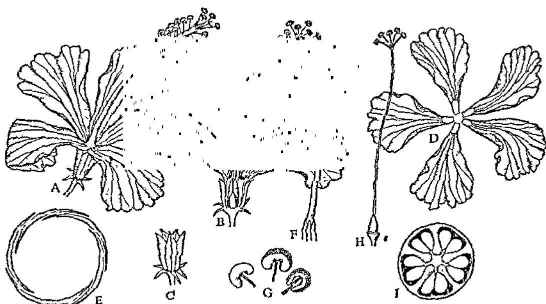


Fig. 758. Floral diagram of *Malvaceae*.

Examples. **Useful plants**—*Gossypium* yields cotton of commerce, rozelle (*Hibiscus sabdariffa*; B. MESTA; H. PATWA) and Madras or Deccan hemp (*H. cannabinus*; B. & H. AMBARI or NALITA) are sources of strong fibres, red or silk cotton tree (*Bombax*)[1] and white cotton tree (*Eriodendron*)—cotton used for stuffing pillows and cushions and wood used for making tea and match-boxes and match-sticks, lady's finger (*Hibiscus esculentus*)—green fruits used as a vegetable, mallow (*Malva*)—green leaves used as a vegetable, etc.; **ornamental**: several species of *Hibiscus*, e.g. shoe-flower or China rose (*H. rosa-sinensis*; B. JABA; H. GURHAL), *H. mutabilis* (B. STHALPADMA; H. & P. GULIAJAIB), etc., and hollyhock (*Althaea*); **shade tree**: Portia tree (*Thespesia*).



Malvaceae. FIG. 759. China rose (*Hibiscus rosa-sinensis*) flower. *A*, an entire flower; *B*, the same split open longitudinally showing the four whorls, more particularly the staminal column with the style passing through it; *C*, calyx with epicalyx; *D*, corolla opened out; *E*, twisted aestivation of corolla; *F*, androecium showing monadelphous stamens; *G*, one-celled anthers—young and mature (dehiscing); *H*, gynoecium showing five carpels united; and *I*, ovary in transection showing axile placentation.

Other common plants of the family—*Sida cordifolia* (B. BERELA; H. BARIARA), *Urena lobata* (B. BAN-OKRA; H. BACHATA), *Hibiscus vitifolius* (B. & H. BAN-KAPAS), Indian mallow (*Abutilon indicum*; B. PETARI; H. KANGHI), *Malachra*

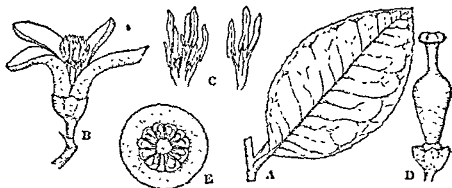
[1] Note that in silk cotton tree (*Bombax*) and white cotton tree (*Eriodendron*) the leaves are palmately compound and the stamens are polyadelphous; these have now been separated to a new family called *Bombacaceae*.

capitata (B. & H. BAN-BHINDI), *Malvastrum*—a weed of waste places.

Description of China Rose Plant (*Hibiscus rosa-sinensis*; fig. 759. A much-branched shrub. **Leaves** simple, alternate, palmately 3-veined at the base, 3-4 inches long, margin serrate, petiole long **Flowers** solitary and axillary on a long peduncle articulated to the pedicel, large and showy, red in colour, regular, bisexual, hypogyrous, bracteoles 5 or more in the form of a whorl known as epicalyx **Calyx** 5-lobed. **Corolla**—5 petals, free, but united at the base with the staminal column or tube; aestivation twisted clockwise or anticlockwise. **Androecium**—stamens numerous, united into a bundle (monadelphous), epipetalous, adnate to the petals at the base, anthers free, reniform, 1 lobed. **Gynoecium**—carpels (5), connate, style passing through the staminal column, stigmas 5, ovary 5-locular; placentation axile **Fruit** not formed; in other species of *Hibiscus* a loculicidal capsule.

Family 8—*Rutaceae* (1,200 sp.—71 sp. in India)

Habit—shrubs and trees (rarely herbs). **Leaves** simple or compound, alternate or opposite, gland-dotted. **Flowers** regular, bisexual and hypogynous; *disc (disk) around the base of the* ovary prominent—either ring-like or lobed. **Calyx**—sepals 4 or 5 (rarely 3), free or slightly connate, imbricate. **Corolla**—petals 4 or 5 (rarely 3), free, imbricate (rarely valvate). **Androecium**—stamens variable in number, generally twice as many as petals or sometimes as many as petals or numerous in *Citrus* and *Aegle*, free or united in irregular bundles (polyadelphous), inserted on a ring- or cup-like disc. **Gynoecium**—carpels generally (4 or 5) or (∞) in *Citrus*, rarely (3-1), syncarpous or free at the base and united above, either sessile or raised on a



Rutaceae. FIG. 760. Sour lime (*Citrus aurantifolia*). *A*, a leaf; *B*, a flower; *C*, stamens (polyadelphous); *D*, pistil; and *E*, section of ovary showing axile placentation.

short gynophore; ovary multilocular, usually 4- or 5-celled or many-celled in *Citrus*, (rarely 1- or few-celled), with axile placentation; ovules 2-∞ (rarely 1) in each cell (loculus), in two rows. **Fruit** a berry capsule or hesperidium (see fig. 319). Seeds with or without endosperm. Polyembryony is frequent

in *Citrus*, e.g. lemon and orange (but not pummelo and citron). *Floral formula*—$K_{4-5} C_{4-5} A_{8, 10 \text{ or } \infty} \underline{G}_{(4, 5 \text{ or } \infty)}$.

Examples. **Useful Plants**—*Citrus* (e.g. lime, lemon, orange, citron and pummelo), wood-apple (*Aegle marmelos*; B. BAEL; H. SIRIPHAL), elepant-apple (*Limonia acidissima*; B. KATH-BAEL; H. & P. KAITH), Chinese box (*Murraya exotica*; B. KAMINI; H. MARCHULA; P. MARUA)—timber useful, curry leaf plant (*M. koenigii*; B. & H. BARSUNGA)—leaves used for flavouring curries, *Peganum harmala* (B. ISBAND; H. HARMAL; P. HURMUL)—seeds yield Turkey-red, etc.

Common species of *Citrus* sour lime (*C. aurantifolia*; B. PATI- or KAGZI-NEBU, H & P NIMBOO), sweet lime (*C limetta*; B MITHA-NEBU or -KAGZI), lemon (*C. limon*, B. NEBU, H. KHATTI), rough lemon (*C. jambhiri*; B JAMIR; H JHAMBHIRI), *C. assamensis* (B ADA-JAMIR)—used for garnishing curries, citron (*C. medica*; B. BARA-NEBU; H. BARA-NIMBOO; P. KHATTA), pummelo or shaddock (*C grandis*; B. BATABI NEBU; H. & P. CHAKOTRA), Mandarin orange (*C. reticulata*, B. KAMALA; H. & P. SANGTRA)—loose-skinned commercial orange, sour or bitter orange (*C. aurantium*)—used in preparing marmalade, sweet orange (*C sinensis*—Malta, Mosambi or Mozambique, and Valentia are varieties of it)—tight-skinned, king orange (*C. nobilis*), wild orange (*C. indica*)—growing wild in Assam, bergamot orange (*C. bergamia*)—bergamot oil is prepared from it, grape-fruit (*C. paradisi*)

Other common plants of the family—rue (*Ruta graveolens*, B. ERMUL; H. SADAB; P. SUDAB)—a strongly smelling small herb, *Glycosmis arborea* (B. ASHHOURA; H. BANNIMBU), *Clausena heptaphylla* (B. KARANPHAL), *C. pentaphylla* (B. & H. PANKARPUR), *Luvunga scandens* (B. & H. LAVANGA-LATA)—a large thorny climbing shrub, *Toddalia* (B. TODALI; H. DAHAN)—a large prickly climbing shrub, *Xanthoxylum*, (B. BAZINALI; H. BADRANG)—a prickly tree, etc.

Description of *Murraya exotica* An evergreen shrub or a small tree. **Leaves** pinnately compound (imparipinnate), leaflets alternate, 3-9, with oblique base. **Flowers** white, fragrant, ¾-1 inch long, in axillary or terminal corymbs, sometimes solitary, regular, bisexual and hypogynous. **Calyx**—sepals 5, connate, minute, glandular. **Corolla**—petals 5, free, oblong-lanceolate, imbricate **Androecium**—stamens 10, free, longer and shorter, inserted on an elongated disk **Gynoecium**—carpels (2), syncarpous; ovary superior, slender, 2-locular (rarely 4- or 5-locular), with a solitary ovule in each loculus, style linear; stigma capitate **Fruit** an ovoid berry, ½ inch long, 1- to 2-seeded, red or deep orange when ripe

Family 9—*Leguminosae*[1] (12,000 sp.—1,088 sp. in India)

Habit—herbs, shrubs, trees and climbers. ***Roots*** of many species, particularly of *Papilionaceae*, have tubercles (see fig. 463). **Leaves** alternate, pinnately compound, rarely simple, as in rattlewort (*Crotalaria sericea*; B. ATASHI; H. JHUNJHUNIA), camel's foot tree (*Bauhinia*; B. KANCHAN; H. KACHNAR), and some species of *Desmodium*, e.g. *D*

[1] This has now been raised to the rank of an 'order' with three 'families'—*Caesalpiniaceae*, *Mimosaceae* and *Papilionaceae*.

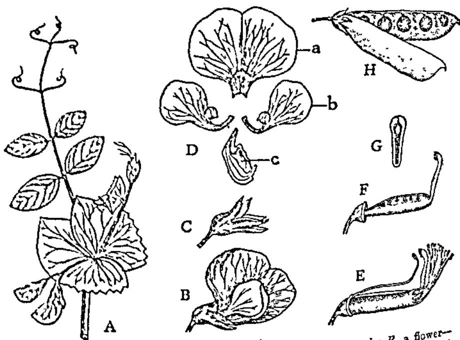
gangeticum, with a swollen leaf-base known as the pulvinus; stipules 2, usually free. **Flowers** bisexual and complete, regular or irregular or zygomorphic, hypogynous or slightly perigynous. **Calyx**—sepals usually (5) with the odd one anterior (away from the axis), sometimes (4), united or free. **Corolla**—petals usually 5 with the odd one posterior (towards the axis), sometimes 4, free or united. **Androecium**—stamens usually 10 or numerous, sometimes less than 10 by abortion, free or united. **Gynoecium**—carpel 1: ovary 1-celled, with 1 to many ovules, superior; placentation marginal; ovary often on a long or short stalk, called stipe or gynophore. **Fruit** a legume or pod.

This is the second biggest family among the 'flowering' plants (being only second to *Compositae*), with varying characters, and as such it has been divided into the following subfamilies. The division is primarily based on the characters of the corolla and the stamens (see figs. 744-6). All these subfamilies are well represented in India. From an economic standpoint this is one of the most important families (see pp. 540-1); probably it ranks second to *Gramineae* in order of importance.

(1) *Papilionaceae* (867 sp. in India). Herbs, shrubs, trees and climbers. **Leaves** simply pinnate, rarely simple; stipels often present. **Inflorescence** usually a raceme. **Flowers** zygomorphic, polypetalous and papilionaceous. **Calyx**—sepals usually (5), gamosepalous, often imbricate, sometimes valvate. **Corolla**—petals usually 5, free, of very unequal sizes, the posterior largest one being the vexillum, the two lateral ones being the wings, and the two innermost ones (apparently united) forming the keel; aestivation of corolla vexillary. **Androecium**—stamens ten, diadelphous—(9) + 1, rarely free or monadelphous, as in coral tree (*Erythrina*). *Floral formula*—$K_{(5)}C_5A_{(9)+1}\underline{G}_1$. For floral diagram see p. 524.

(2) *Caesalpinieae* (125 sp. in India). Shrubs and trees, rarely climbers or herbs. **Leaves** simply pinnate or bipinnate, rarely simple, as in camel's foot tree (*Bauhinia*); stipels absent. **Inflorescence** commonly a raceme. **Flowers** zygomorphic or irregular and polypetalous. **Calyx**—sepals usually 5, polysepalous (sometimes gamosepalous), imbricate. **Corolla**—petals usually 5, free, sub-equal or unequal, the odd or posterior one (sometimes very small) always innermost; aestivation of corolla imbricate. **Androecium**—stamens ten or fewer by abortion, free. *Floral formula*—$K_5C_5A_{10}\underline{G}_1$. For floral diagram see p. 524.

(3) *Mimoseae* (96 sp. in India). Shrubs and trees, sometimes herbs. **Leaves** bipinnate; stipels present or absent. **Inflorescence** a head or a spike. **Flowers** regular, often small and aggregated in spherical heads. **Calyx**—sepals (5) or (4), generally gamosepalous, valvate. **Corolla**—petals (5) or (4) mostly gamopetalous; aestivation of corolla valvate. **Androecium**—stamens mostly numerous, sometimes 10, 8 or 4, free, sometimes united at the base; pollen grains often united in small masses. *Floral formula*—$K_{(4-5)}\,C_{(4-5)}\,A_{4,\,8,\,10\text{ or }\infty}\,\underline{G}_1$. For floral diagram see p. 524.



Papilionaceae. Fig. 761. Pea (*Pisum sativum*). *A*, a branch; *B*, a flower—papilionaceous (see also figs. 226-8); *C*, calyx; *D*, corolla—petals opened out (*a*, vexillum, *b*, wing; *c*, keel); *E*, stamens—(9)+1, and pistil; *F*, pistil—1 carpel (note the ovary, style and stigma); *G*, ovary in section showing marginal placentation; and *H*, a fruit—legume

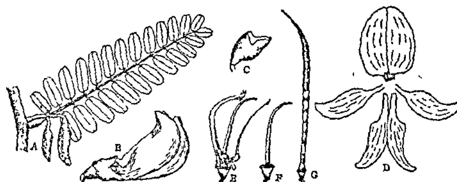
Examples of *Papilionaceae.* **Useful plants—pulses** (rich in proteins): gram (*Cicer arietinum*), lentil (*Lens culinaris*; B. & H. MASUR), pigeon pea (*Cajanus cajan*; B. ARAHAR; H. RAHAR), pea (*Pisum sativum*; B. & H. MATAR), green gram (*Phaseolus aureus*; B. & H. MOONG), black gram MASH; H. URID), *Lathyrus sativus* (B (*Glycine max*), broad bean (*Vicia* country bean (*Dolichos lablab*), cow (C BARBATI; P. RAUNG), swor bean (*Phaseolus vulgari*

cannabina (B. DHAINCHA), sesban (*S. sesban*; B. JAINTI; H. JAINT; P. JAINTOR), lucerne or alfalfa (*Medicago sativa*—also an excellent fodder), *Tephrosia candida* and *Derris robusta* grown in tea gardens, etc.; **timber trees:** Indian redwood (*Dalbergia sissoo*; B. SISSOO; H. & P. SHISHAM) and Indian rosewood (*D. latifolia*; B. SITSAL); **other useful plants**. ground nut (*Arachis hypogaea*; see fig. 501), pith plant (*Aeschynomene indica*; B. & H. SHOLA), Indian hemp (*Crotalaria juncea*; B. SHONE; H. & P. SAN), *Trigonella* (B. METHI), indigo (*Indigofera*), *Derris elliptica*—a woody climber, roots used as a valuable insecticide and also used for poisoning fishes in the tank, Indian liquorice or crab's eye (*Abrus precatorius*; B. KUNCH; H. RATTI; P. RATAK), sweet pea (*Lathyrus odoratus*)—ornamental, lupin (*Lupinus*)—ornamental and a fodder, etc.

Other common plants of the family—rattlewort (*Crotalaria sericea*; B. ATASHI; H. JHUNJHUNIA), butterfly pea (*Clitoria ternatea*; B. APARAJITA; H. APARAJIT), *Sesbania grandiflora* (B. BAKPHUL; H. AGAST), coral tree (*Erythrina indica*; B. MANDAR; H. PANJIRA), parrot tree or flame of the forest (*Butea monosperma*; B. PALAS; H. DHAK), Indian telegraph plant (*Desmodium gyrans*; B. BAN-CHANDAL; H. BAN-CHAL), *Desmodium gangeticum*, cowage (*Mucuna pruriens*; B. ALKUSHI; H. KAWANCH—fruits with stinging hairs), wild pea (*Lathyrus aphaca*), etc.

(*a*) **Description of Pea Plant** (*Pisum sativum*; fig. 761). Pea plant is a cultivated annual herb, climbing by tendrils which are modifications of the upper leaflets. **Roots** are provided with nodules (see fig. 463) for nitrogen fixation. **Leaves** p[illegible] ets, terminal ones being modifie[illegible] as pulvinus; stipules foliaceous [illegible] or in a few-flowered raceme, [illegible] gynous, and papilionaceous. **Calyx**—sepals 5, unequal, united into an oblique tube, 5-lobed. **Corolla**—petals 5, free, papilionaceous, with vexillary aestivation—the outermost petal known as the standard is broad, the lateral two are the wings, enclosing the two innermost ones—the keel. **Androecium**—stamens ten, (9)+1, diadelphous **Gynoecium**—carpel 1; ovary subsessile, one-chambered and few-ovuled; placentation marginal; style one, inflexed, bearded on the inner side Flowers secrete honey, and are protandrous; self-pollination normally occurs in this plant but cross-pollination may be brought about by minute insects **Fruit** a pod or legume, with a few seeds; the pod dehisces by both sutures. **Seeds** exalbuminous (see fig. 3); germination hypogeal (see fig. 12).

(*b*) **Description of** *Sesbania grandiflora* (fig. 762). A soft-wooded tree. **Leaves** pinnately compound, ½-1 ft. long, evenly pinnate, with pulvinus; stipules present. **Inflorescence** an axillary raceme. **Flowers** large, 3 inches long, white or reddish, zygomorphic, papilionaceous, bisexual, hypogynous. **Calyx**—sepals (5), connate, shallowly 2-lipped or 5-toothed **Corolla**—petals (5), free, much exserted, papilionaceous, distinctly clawed; aestivation vexillary. **Androecium**—stamens ten, (9)+1, diadelphous. **Gynoecium**—carpel 1; ovary linear, incurved, unilocular with marginal placentation; ovules many; stigma terminal. **Fruit** a long, narrow pod—1 foot or more long, septate.

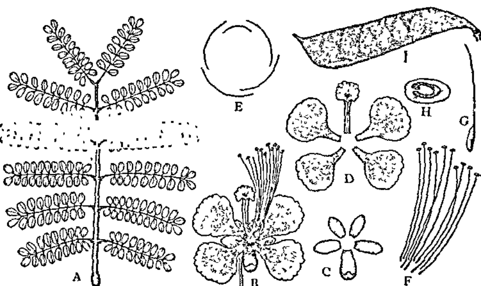


Papilionaceae. FIG. 762. *Sesbania grandiflora*. *A*, a leafy branch; *B*, a flower (papilionaceous), *C*, calyx; *D*, corolla—petals dissected out; *E*, stamens (diadelphous) and pistil; *F*, pistil (one carpel); and *G*, a fruit partially opened up.

(c) **Description of** *Lathyrus aphaca*. Wild pea (*Lathyrus aphaca*) is a much-branched annual
fied into a tendril (see f
long), broad, ovate, lea
peduncle which is 1-2 i
hypogynous. **Calyx** ca
about double the lengt
vexillary. **Androecium**—stamens ten, (9)+1, diadelphous. **Gynoecium**—carpel 1; ovary sub-sessile; placentation marginal; style bearded; stigma capitate. **Fruit** a legume, linear-oblong, $\frac{3}{4}$-$1\frac{1}{2}$ inches long, 4- to 6-seeded.

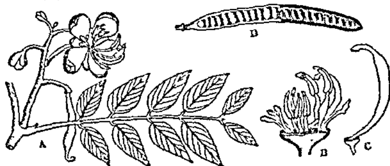
Examples of *Caesalpinieae*. **Useful plants**—tamarind (*Tamarindus indica*)—fruits widely used for sour preparations, Indian laburnum (*Cassia fistula*; B. SHONDAL; H. & P. AMALTASH)—heartwood very hard and durable, and flowers ornamental, etc.; **medicinal:** Indian senna (*Cassia angustifolia*; B. SONAPAT or SONAMUKHI; H. SANAKKAPAT), *Saraca indica* (B. ASOK; H. SEETA-ASOK), fever nut (*Caesalpinia bonducella*; B. NATA; H. KAT-KARANGA; P. BEL KARANJWA), etc.; **dye:** sappan or Brazil wood (*Caesalpinia sappan*; B. & H. BAKAM)—wood yields a valuable red dye extensively used for dyeing silk and wool, starch coloured with this dye forms 'ABIR' used in 'HOLI' festival, and pods yield a high percentage of tannin; **ornamental:** camel's foot tree (*Bauhinia purpurea* and *B. variegata*; B. KANCHAN; H. & P. KACHNAR), gold mohur (*Delonix regia*; B. KRISHNACHURA; H. GULMOHR), dwarf gold mohur or peacock flower (*Caesalpinia pulcherrima*; B. RADHACHURA; H. GULETURA—fig. 763), Jerusalem thorn (*Parkinsonia aculeata*) and *Peltophorum*.

Other common plants of the family—*Cassia sophera* (B. KALKASUNDE; H. KASUNDA), *C. occidentalis* (B. BARA-KALKASUNDE; H. BARA-KASUNDA), ringworm shrub (*C. alata*; B. & H. DAD-MARDAN), *C. tora* (B. & H. CHAKUNDA), etc.



Caesalpinieae. FIG. 763. Dwarf gold mohur (*Caesalpinia pulcherrima*). *A*, a pinnately compound leaf; *B*, a flower; *C*, calyx; *D*, corolla—petals dissected out; *E*, aestivation (imbricate); *F*, stamens, *G*, pistil (one carpel); *H*, ovary in transection showing marginal placentation; and *I*, a fruit.

Description of *Cassia sophera* (fig. 764) An under-shrub **Leaves** alternate, compound, even-pinnate, with a gland on the petiole, leaflets 6-12 pairs, lanceolate **Inflorescence** an axillary raceme. **Flowers** zygomorphic, bisexual, hypogynous, yellow in colour. **Calyx**—sepals 5, free, imbricate.



Caesalpinieae. FIG. 764. *Cassia sophera.* *A*, a branch with inflorescence; *B*, stamens and pistil; *C*, pistil (one carpel); and *D*, a fruit partially opened up

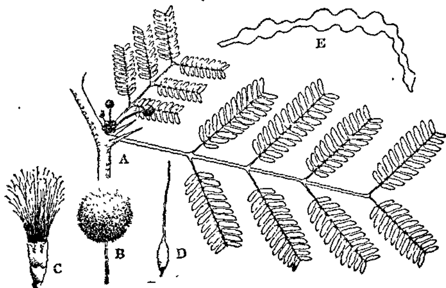
Corolla—petals 5, free, sub-equal, imbricate, with veins. **Androecium**—stamens 10, free, unequal, often 6 or 7 perfect and the rest very small and sterile; anther dehiscing by an apical pore. **Gynoecium**—carpel 1; ovary curved, stalked (stipitate), 1-celled and many-ovuled. **Fruit** a cylindrical pod, septate within, about 4 inches long, with many seeds.

Examples of *Mimoseae*. **Useful plants**—catechu (*Acacia catechu*; B. KHAIR; H. & P. KATHA)—catechu, a kind of tannin, is obtained by boiling chips of heartwood, *A. arabica* (B. BABLA; H. BABUL; P. KIKAR) and *A senegal* yield gums; tannin

and also fuel are obtained from many species of *Acacia*, *Albizzia lebbek* (B. & H. SIRISH)—a timber tree, *A. procera*—wood suitable for tea boxes, many species of *Albizzia* are sources of fuel, rain tree (*Enterolobium saman*)—planted as a shade tree, and *Parkia*—a handsome avenue tree.

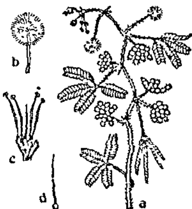
Other common plants of the family—sensitive plant (*Mimosa pudica*; B. LAJJABATI-LATA; H. & P. LAJWANTI or CHUI-MUI), *Neptunia oleracea* (B. & H. PANI-LAJUK), *Pithecolobium dulce* (B. & H. DEKANI-BABUL), nicker bean (*Entada scandens*; B. GILA), and *Prosopis spicigera* (B. & H. SHOMI, P. JHAND).

(*a*) **Description of** *Acacia arabica* (fig. 765) A tree. **Leaves** alternate, pinnately compound, evenly bipinnate, leaflets very small. Stipules modified into two long and straight spines. **Inflorescence** a globose head. **Flowers** regular, bisexual and hypogynous, yellow in colour. **Calyx**—sepals (5) or (4), gamosepalous. **Corolla**—petals (5) or (4), gamopetalous; aestivation valvate. **Androecium**—stamens many, exserted, free or slightly connate at the base; pollen masses 24 in each cell. **Gynoecium**—carpel 1; ovary sessile, 1-celled and many-ovuled, with slender style and small terminal stigma. **Fruit** a pod (lomentum), 4-6 inches long.



(*b*) **Description of** *Albizzia lebbek*. A large tree, deciduous. **Leaves** compound, evenly bipinnate, petiole about 5 inches long, usually with a large gland; glands also often present between pairs of leaflets; **leaflets** 5-9 pairs, each leaflet 1-2 inches long, oblique. **Flowers** in peduncled **heads**, solitary or in fascicles, regular, bisexual, hypogynous; bracts linear, caducous. **Calyx** campanulate, short, hairy, 5-toothed. **Corolla** greenish-yellow,

about ½ inch, gamopetalous; 5-lobed, hairy. **Androecium**—stamens many, united at the base; filaments far exserted **Gynoecium**—carpel 1; ovary superior, 1-celled, many-ovuled; style slender; stigma capitate. **Fruit** a pod, 3-12 inches long, thin flat and straight.

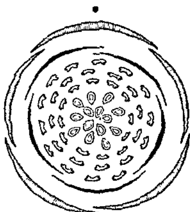


Mimoseae. FIG. 766. Sensitive plant (*Mimosa pudica*). *a*, a branch; *b*, an inflorescence; *c*, a flower; and *d*, pistil (one carpel).

(c) Description of Sensitive Plant (*Mimosa pudica*; fig. 766). A sturdy annual weed. Stem and branches with prickles and bristles. Roots with tubercles. **Leaves** compound, bipinnate, with distinct pulvinus, sensitive to contact; leaflets small, many, in 12-20 pairs, petiole beset with bristles; stipules modified into spines; stipels present. **Inflorescence** a globose head, axillary, ½ inch across, pink in colour **Calyx**—sepals (4), connate. **Corolla**—petals (4), connate; aestivation valvate. **Androecium**—stamens 4, free, much exserted. **Gynoecium**—carpel 1; style filiform; stigma minute; placentation marginal. **Fruit** a pod (lomentum), ½-1 inch long, 3-4 seeded; sutures of pod bristly.

Family 10—*Rosaceae* (2,000 sp.—257 sp. in India)

Habit—herbs, shrubs, trees and climbers. **Leaves** simple or compound, alternate; stipules 2, often adnate to the petiole **Inflorescence**—flowers solitary or in terminal cymes or racemes **Flowers** (see fig. 268) regular, bisexual, rosaceous, typically perigynous with the receptacle hollowed and cup-shaped, rarely epigynous (as in apple and pear). Disc often present in the form of a ring. **Calyx**—sepals 5, adnate to the receptacle lobes free, sometimes with *epicalyx*. **Corolla**—petals 5 (many in cultivated roses), free, usually imbricate, alternating with the sepals, usually white or pink. **Androecium**—stamens numerous, incurved in the bud, arranged in cyclic order, rarely few. **Gynoecium**—carpels usually numerous, free (as in rose) or sometimes (5), united (as in apple and pear) or only 1 (as in plum and peach); ovary unilocular or 5-locular in syncarpous pistil, with 1, 2 or 3 ovules in each loculus; ovules anatropous and pendulous. **Fruit** varying—drupe, follicle, berry, achene or pome. **Seeds** exalbuminous. *Floral formula*—$K_5 C_5 A \infty \underline{G} \infty$ or (5) or 1.


FIG. 767. Floral diagram of *Rosaceae*.

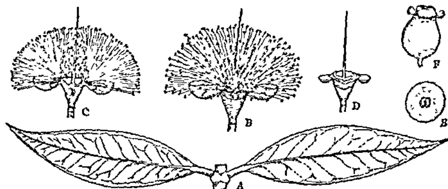
Economically this is an important family. Otto of rose is mostly obtained from *Rosa damascena* and *R. centifolia*; there are many fleshy edible fruits, e.g. plum, peach, prune, apricot, strawberry, apple, pear, etc., and several varieties of rose are ornamental garden plants.

Examples. Rose (*Rosa*) with 150 species, e.g. dog rose (*R. involucrata*) with five petals, wild rose (*R. gigantea*), Damask or Bussora rose (*R. damascena* and *R. centifolia*), musk rose (*R. moschata*), *R. indica*, *R.*

etc., and several hybrids, loquat (*Eriobotrya japonica*), plum (*Prunus communis*), peach (*P. persica*), prune (*P. domestica*), apricot (*P. armeniaca*), almond (*P. amygdalus*), cherry (*P. avium*), quince (*Cydonia oblonga*), strawberry (*Fragaria vesca*) wild strawberry (*F. indica*), apple (*Malus sylvestris*), pear (*Pyrus communis* and *P. pyrifolia*), silverweed (*Potentilla fulgens*), raspberry (*Rubus idaeus*), wild raspberry (*R. moluccanus*), and many other wild species in the hills.

Family 11—*Myrtaceae* (2,800 sp.—116 sp. in India)

[illegible] ral bundles and also [illegible] gland-dotted. **Flowers** [illegible] **Calyx**—sepals (4-5) [illegible] or imbricate **Corolla**—petals 4-5, free, imbricate. **Androecium**—stamens numerous (rarely few) free, sometimes polyadelphous, epigynous. **Gynoecium**—carpels (2-5) or (∞),



Myrtaceae. FIG. 768. Rose-apple (*Syzygium jambos*). *A*, opposite leaves; *B*, a flower; *C*, a flower cut longitudinally; *D*, pistil; *E*, section of ovary showing axile placentation; and *F*, a fruit.

syncarpous; ovary crowned by a disc, inferior, 1- to 2-locular, sometimes multilocular with one to many ovules in each loculus; placentation axile (rarely parietal). **Fruit** a berry or capsule, inferior, usually with persistent calyx. **Seed** exalbuminous. *Floral formula*—$K_{4-5}\, C_{4-5}\, A\infty\, \bar{G}_{(2-5)}$ or (∞)

Examples. **Useful plants**—*Eucalyptus*—leaves yield eucalyptus oil, guava (*Psidium guayava*), clove (*Syzygium aromaticum*), black berry (*S. cumini*; B. KALA-JAM; H. & P. JAMAN), wild berry (*S. fruticosum*; B. BAN-JAM), rose-apple (*S. jambos*; B. GOLAP-JAM; H. & P. GULAB-JAMAN), Malay apple (*S. malaccense*; B. JAMRUL), allspice or pimento (*Pimenta officinalis*)—dried unripe fruits form allspice which combines the flavour of cloves, nutmeg and cinnamon, cajeput (*Melaleuca*)—leaves yield cajeput oil, etc.

Other common plants of the family—*Barringtonia acutangula* (B. & H. HIJAL), myrtle (*Myrtus communis*), bottlebrush tree (*Callistemon linearis*), etc.

Family 12—*Cucurbitaceae* (800 sp.—87 sp. in India)

Habit—tendril climbers; tendrils extra-axillary, simple or branched. **Leaves** simple, alternate and palmately veined. **Flowers** regular, unisexual, epigynous and monoecious or dioecious. **Calyx**—sepals (5), united, often deeply 5-lobed. **Corolla**—petals (5), united, often deeply 5-lobed, imbricate; inserted on the calyx-tube.

Male Flowers: **androecium**—stamens usually 3, sometimes 5, varying in character; sometimes they are free but more commonly they are united in a pair (or in 2 pairs when stamens 5) throughout their whole length (*synandrous*), the odd one remaining free; in some cases the anthers only are united (*syngenesious*); each anther 1-lobed or 2-lobed; paired stamens have either 2-lobed or 4-lobed anthers; anther-lobes variously folded or *sinuous*, i.e. twisted like a transverse S. Rudiments of the pistil sometimes present.

Female Flowers: **gynoecium**—carpels (3), syncarpous; ovary inferior, unilocular and placentation parietal but often the

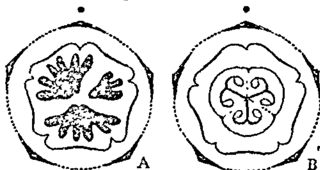
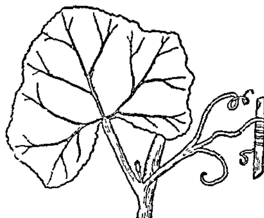


FIG. 769. Floral diagrams of *Cucurbitaceae*; *A*, male flower; *B*, female flower.

placentae intrude far into the chamber of the ovary making the latter falsely trilocular; ovules many; style 1; stigmas 3 which are often forked. **Fruit** a pepo. *Floral formulae—male flower:* $K_{(5)}\,C_{(5)}\,A_{3\ or\ 5}$, and *female flower:* $K_{(5)}\,C_{(5)}\,\overline{G}_{(3)}$.



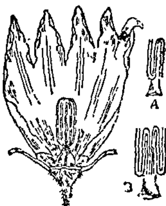


FIG. 770 FIG. 771

Cucurbitaceae. Fig. 770. Gourd (*Cucurbita pepo*). Portion of a branch with a leaf and a tendril. Fig. 771. Male flower of the same. *A*, one stamen; *B*, two stamens united together.

Plants of this family are mostly used as vegetables, a few yield delicious summer fruits, and a few are medicinal.

Examples: sweet gourd or pumpkin (*Cucurbita moschata*), gourd or vegetable marrow (*C. pepo*; B. KUMRA; H. HALWA-KADDU), snake gourd (*Trichosanthes anguina*; B. CHICHINGA; H. & P. CHACHINDA), *T. dioica* (B. PATAL; H. PARWAL), bitter gourds (*Momordica charantia*; B. UCHCHE and KAKALA; H. KARELI, P. KARELA), *M. cochinchinensis* (B. KAKROL; H. CHATTHAI), bottle gourd (*Lagenaria siceraria*; B. LAU; H. LAUKI; P. GHIYA), ash or wax gourd (*Benincasa cerifera*; B. CHAL-KUMRA; H. & P. PETHA), ribbed gourd (*Luffa acutangula*; B. JHINGA; H. & P. KALI-TORI), bath sponge or loofah (*L. cylindrica*; B. DHUNDUL; H. & P. GHIYA-TORI), *Coccinia cordifolia* (B. TELAKUCHA; H. BHIMBA; P. GHOL), squash (*Sechium edule*), cucumber (*Cucumis sativus*; B. SASHA; H. & P. KHIRA), melon (*C. melo*; B. PHUTI; H. & P. KHARBUZA, PHUTI and KAKRI), water melon (*Citrullus vulgaris*; B. TARMUZ; H. & P. TARBUZA), colocynth (*C. colocynthis*; B. MAKAL; H. INDRAYAN; P. TUMMA)—medicinal, and *Bryonia*—medicinal.

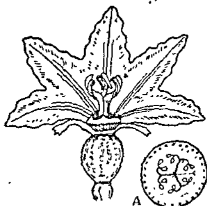


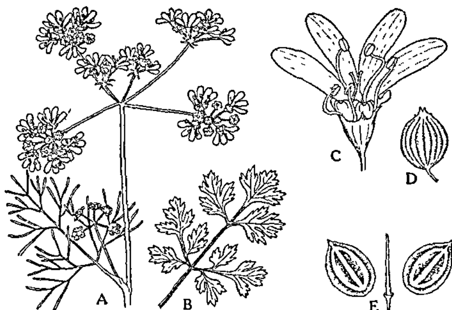
FIG. 772. Female flower of *Cucurbita pepo*. *A*, ovary in transverse section showing placentation.

Description of Gourd Plant (*Cucurbita pepo*; figs. 770-2). A large climbing herb, hairy all over; tendril opposite leaf, 2- to 4-fid. **Leaves** broad, long-petioled, palmately veined. **Flowers** solitary, large, yellow in colour, regular, unisexual (monoecious). **Calyx**—sepals (5), connate; lobes linear or leafy. **Corolla**—petals (5), connate, campanulate. *In male flowers* [illegible] air, the odd one remaining free; [illegible] elled, sinuous. *In female flowers* [illegible] ovary inferior, 1-celled; placent[illegible] each forked. **Fruit** a large fleshy pepo. Seeds [illegible] ssed.

Family 13—*Umbelliferae* (2,700 sp.—180 sp. in India)

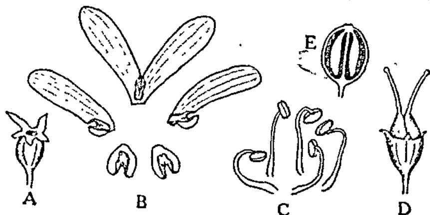
Habit—herbs (rarely shrubs); stem usually fistular. **Leaves** alternate, simple or usually much dissected, often *decompound*; petiole usually sheathing at the base. **Inflorescence** an umbel, usually compound or [illegible] (actinomorphic) or som[illegible] or polygamous, outer flowers [illegible] teoles involucrate. **Calyx**—sepals 5, free, adnate to the ovary. **Corolla**—petals 5, free adnate to the ovary, sometimes

unequal, margin often incurved, usually imbricate. **Androecium**—stamens 5, free, alternating with the petals, epigynous;



Umbelliferae. FIG. 773. Coriander (*Coriandrum*). *A*, a branch with leaf and inflorescence (compound umbel); *B*, a lower leaf; *C*, a flower; *D*, a fruit; and *E*, a fruit broken up into two mericarps, and the carpophore.

anthers versatile. **Gynoecium**—carpels (2), syncarpous; ovary inferior, 2-celled, crowned by a 2-lobed disk; styles 2; stigmas capitate; ovules 2, solitary in each cell, pendulous. **Fruit** a cremocarp consisting of two indehiscent carpels laterally or dorsally compressed, breaking up into two parts, called *mericarps*, each attached to a slender, often forked axis (*carpophore*);



Umbelliferae (contd.). FIG. 774. *A*, calyx with inferior ovary; *B*, petals dissected out; *C*, stamens dissected out; *D*, pistil; and *E*, ovary in longitudinal section.

the mericarps usually with five longitudinal ridges and traversed by oil-canals (*vittae*). Seeds 2, solitary in each carpel, albuminous. *Floral formula*—$K_5 C_5 A_5 \overline{G}_{(2)}$.

Examples. **Useful plants**—coriander (*Coriandrum sativum*; B., H. & P. DHANIA), anise or fennel (*Foeniculum vulgare*; B. PAN-MOURI; H. & P. SAUNF), *Carum copticum* (B. JOWAN; H. & P. AJOWAN), *C. roxburghianum* (B. RANDHANI), carraway (*C. curvi*; B. & H. SHAJIRA), cumin (*Cuminum cyminum*; B. JIRA; H. SAFED-JIRA), parsnip (*Peucedanum*; B. SULPA; H. SOWA), carrot (*Daucus carota*; B. & H. GAJOR), asafoetida (*Ferula foetida*; B., H. & P. HING), celery (*Apium graveolens*), etc.

Other common plants of the family—*Eryngium foetidum*—(B. BAN-DHANIA), Indian pennywort (*Centella asiatica*; B. THULKURI; H. & P. BRAHMI-BOOTI), *C. rotundifolia*, dropwort (*Oenanthe*)—a common weed of wet places, etc.

SUB-CLASS II. GAMOPETALAE

Family 14—*Compositae* (14,100 sp.—696 sp. in India)

Habit—herbs and shrubs. **Leaves** simple, alternate or opposite, rarely compound. **Inflorescence** a head (or capitulum) with an involucre of bracts. **Flowers** (florets) either all tubular or all ligulate, or the central florets tubular and the marginal ones ligulate; the central tubular florets are known as *disc* florets and the marginal ligulate ones as *ray* florets.

Disc Florets: regular, tubular, bisexual and epigynous, each usually in the axil of a bracteole. **Calyx** often modified into a cluster of hairs called pappus, as in *Tridax* and *Ageratum*, or into scales, as in sunflower and *Eclipta*, or absent, as in water cress (*Enhydra*). **Corolla**—petals (5), gamopetalous, tubular. **Androecium**—stamens 5, epipetalous, filaments free but anthers united (syngenesious). **Gynoecium**—carpels (2), syncarpous; ovary inferior, 1-celled, with one basal, anatropous ovule; style 1; stigmas bifid. **Fruit** a cypsela. *Floral formula*—K pappus or 0 $\overline{C_{(5)}A_{(5)}}\overline{G}_{(2)}$.

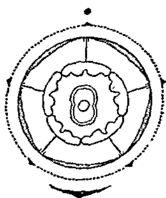


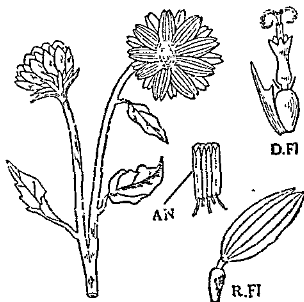
FIG. 775. Floral diagram of *Compositae* (disc floret).

Ray Florets: zygomorphic, ligulate, unisexual (female) or sometimes neuter, as in sunflower, and epigynous, each usually in the axil of a bracteole.

Calyx usually modified into pappus, sometimes it is sca... absent. **Corolla**—petals (5), gamopetalous, ligulate (... shaped). **Gynoecium,** as in the disc florets. **Fruit** the sa... *Floral formula—K pappus or 0* $C_{(5)}\,A_0\,\overline{G}_{(2)\text{ or }0}$.

Examples. **Useful plants—medicinal:** Indian wormwood (*Artemisia vulgaris*; B. NAGDONA; H. NAGDUNA), santonin (*A. cina*), *Vernonia anthelmintica* (B. SOMRAJ; H. KALIZIRI), *Eupatorium ayapana* (B. AYAPANA), *Wedelia calendulacea* (B. BHIMRAJ; H. & P. BHANGRA), *Eclipta alba* (B. KESHUTI; H. & P. SAFED BHANGRA), etc.; **vegetables:** chicory (*Cichorium intybus*; H. & P. KASNI), endive (*C. endivia*), lettuce (*Lactuca sativa*), globe artichoke (*Cynara*), Jerusalem artichoke (*Helianthus tuberosus*; B. HATICHOKE), etc.; **oils:** safflower (*Carthamus tinctorius*; B. KUSHUM-PHUL; H. & P. KUSAM—also a source of dye), sunflower (*Helianthus annuus*; fig. 776), etc.; **insecticides:** a few species of *Chrysanthemum* (*Pyrethrum*), e.g. *C. cinerariefolium* yielding more or less 1% pyrethrin; **ornamental:** sunflower, *Zinnia, Cosmos, Dahlia,* daisy (*Bellis*), *Calendula, Chrysanthemum* (B. CHANDRA-MALLIKA; H. GULDAUDI; P. GUL-DAUD), *Aster, Gerbera,* marigold (*Tagetes patula*), everlasting flower (*Helichrysum*), etc.

Other common plants of the family—goat-weed (*Ageratum conyzoides*) with purplish heads, *Blumea lacera* (B. KUKURSONGA; H. & P. KOKRONDA), globe thistle (*Echinops*), *Eupatorium odoratum*—a common scandent shrub, *Enhydra fluctuans* (B. HALENCHA; H. HARUCH), elephant's foot (*Elephantopus scaber*; B. & H. HASTIPADA or GOBHI), *Sonchus*—an annual weed with latex, *Tridax procumbens* (fig. 777)—a common decumbent weed, cockle-bur (*Xanthium strumarium*;

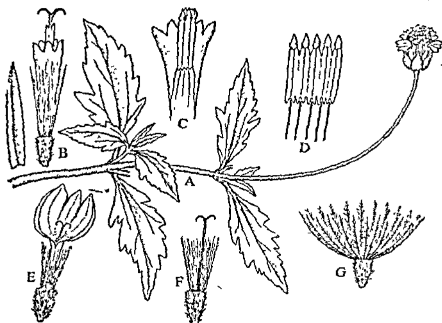


Compositae. FIG. 776. Sunflower (*Helianthus annuus*). A portion of a branch (on the left); *D.Fl*, disc floret (bisexual) with a bracteole (at the base); *AN*, anthers (syngenesious); and *R Fl*, ray floret (neuter).

B. & H. OKRA), *Mikania scandens*—a twiner, *Vernonia cinerea* (B. KUKSHIM; H. & P. SAHADEVI), and *V. arborea*—a tree.

(*a*) **Description of Sunflower Plant** (*Helianthus annuus*; fig. 776). Sunflower is an annual garden herb **Leaves** simple, opposite, often the upper ones alternate **Inflorescence** head or capitulum, large (in some cases very large), with an involucre of bracts, usually 3-seriate. **Flowers**—central florets, called disc florets, are tubular and bisexual, and marginal florets, called *ray* florets, are zygomorphic, ligulate and neuter. *Disc florets*—regular, tubular, bisexual and epigynous **Calyx** modified into *two scales*. **Corolla** gamopetalous, 5-lobed **Androecium**—stamens 5, epipetalous and *syngenesious*. **Gynoecium**—carpels (2), syncarpous; ovary inferior, 1-celled, with one basal ovule; style 1, but stigmas 2. **Fruit** a cypsela. *Ray florets*—zygomorphic, ligulate, neuter and epigynous. **Calyx**, as in disc florets or absent. **Corolla** ligulate, 5-lobed. **Stamens** absent. **Gynoecium**, as in disc florets, but *style* and stigmas absent making the flower neuter.

(*b*) **Description of** *Tridax procumbens* (fig. 777). A weak decumbent perennial herb. **Leaves** simple, opposite, 1-3 inches long, toothed or lobed. **Inflorescence** a head, solitary, on long peduncle, heterogamous, consisting of



Compositae. FIG. 777. *Tridax procumbens.* *A*, a branch with an inflorescence (head); *B*, a disc floret with a bracteole; *C*, corolla (split open) and epipetalous stamens; *D*, syngenesious stamens (split open); *E*, a ray floret; *F*, pistil and pappus; and *G*, a fruit (cypsela) with pappus (parachute mechanism).

pale yellow ray (ligulate) florets and deep yellow disc (tubular) florets. Involucre campanulate, bracts usually biseriate; receptacle slightly convex. *Disc florets*—regular, bisexual, tubular; bracteole thin, membranous, persistent. **Calyx** modified [illegible] la gamopetalous, tubular, 5-lobed, [illegible] syngenesious, epipetalous; anthers [illegible] (2), syncarpous, style passing thr[illegible] na 2-fid, hairy; ovary inferior, 1-celled, with one ovule. **Fruit** a cypsela, hairy, with bristly pappus. *Ray florets*—zygomorphic, unisexual, female, ligulate,

3-lobed; bracteole membranous, slightly coloured. **Calyx**, as in disc floret. **Corolla** gamopetalous, ligulate, pale yellow, 3-fid. **Gynoecium**—carpels (2), syncarpous; stigma 2-fid; ovary, as in disc florets. **Fruit**, as in disc florets.

(c) **Description of** *Sonchus asper*. An annual weed, 2-3 ft. tall, with milky juice. **Stem** fistular, grooved. **Leaves** radical (stalked), 6-10 inches long, and cauline (often semi-amplexicaul, i.e. stem-clasping), toothed (spinous) or pinnatifid. **Inflorescence**—terminal heads in sub-corymbose or umbellate panicle; involucre ovoid, often thickened at the base; bracts multi-seriate, glabrous. **Flowers** homogamous, all ligulate, yellow; receptacle flat, naked. **Sepals** represented by pappus, multi-seriate, white, united at the base. **Petals** connate in a ligulate corolla, 5-toothed. **Stamens** 5, syngenesious, epipetalous; anthers sagittate. **Carpels** (2), syncarpous **Fruit** a cypsela, compressed, ribbed, with copious pappus.

Family 15—*Apocynaceae* (1,400 sp.—84 sp. in India)

Habit—herbs, shrubs, trees, twiners and lianes; with latex; bicollateral bundles. **Leaves** simple, opposite or whorled, rarely alternate. **Flowers** regular, bisexual and hypogynous, in cymes, usually salver- or funnel-shaped, often with corona. **Calyx**—sepals (5), rarely (4), gamosepalous, imbricate. **Corolla**—petals (5), rarely (4), gamopetalous, twisted. **Androecium**—stamens 5, rarely 4, epipetalous, included within the corolla-tube; anthers usually connate around the stigma and apparently adnate to it. **Disc** present, ring-like or glandular. **Gynoecium**—carpels 2 or (2), apocarpous or syncarpous, superior. When apocarpous each ovary is 1-celled with marginal placentation, and when syncarpous the ovary may be 1-celled with parietal placentation, or 2-celled with axile placentation; ovules 2 - ∞ in each. **Fruit** a pair of follicles or berries or drupes. **Seeds** often with a crown of long silky hairs; mostly with endosperm. *Floral formula*—$K_{(5)}\overline{C_{(5)}A_5}\underline{G}_{(2)\text{ or }2}$.

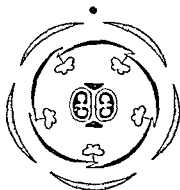


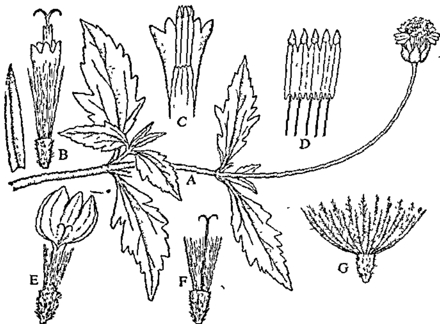
FIG. 778. Floral diagram of *Apocynaceae*.

Examples. **Useful plants—medicinal**: *Rauwolfia serpentina* (B. CHANDRA or SARPAGANDHA; H. & P. SARP GAND or CHOTA CHAND), *Holarrhena antidysenterica* (B. KURCHI; H. KARCHI; P. KAWAR), *Wrightia tomentosa* (B. DUDH-KHOROI; H. DUDHI), yellow oleander (*Thevetia peruviana*; B. KALKE-PHUL; H. & P. PILA-KANER)—seeds very poisonous, devil tree (*Alstonia scholaris*; B. CHHATIM; H. CHATIUM; P. SATONA; **fruits**: *Carissa carandas* (B. KARANJA; H. & P. KARONDA)—a thorny shrub, and *Willughbeia* (B. LATA-AM); **ornamental**: herb—periwinkle (*Vinca rosea*; B. NAYANTARA; H. SADA-BAHAR); shrubs—oleander (*Nerium indicum*; B. KARAVI; H. & P.

B. & H. OKRA), *Mikania scandens*—a twiner, *Vernonia cinerea* (B. KUKSHIM; H. & P. SAHADEVI), and *V. arborea*—a tree.

(*a*) **Description of Sunflower Plant** (*Helianthus annuus*; fig. 776). Sunflower is an annual garden herb. **Leaves** simple, opposite, often the upper ones alternate **Inflorescence** head or capitulum, large (in some cases very large), with an involucre of bracts, usually 3-seriate. **Flowers**—central florets, called disc florets, are tubular and bisexual, and marginal florets, called ray florets, are zygomorphic, ligulate and neuter. *Disc florets*—regular, tubular, bisexual and epigynous **Calyx** modified into two scales **Corolla** gamopetalous, 5-lobed **Androecium**—stamens 5, epipetalous and syngenesious. **Gynoecium**—carpels (2), syncarpous; ovary inferior, 1-celled, with one basal ovule; style 1, but stigmas 2. **Fruit** a cypsela. *Ray florets*—zygomorphic, ligulate, neuter and epigynous. **Calyx**, as in disc florets or absent. **Corolla** ligulate, 5-lobed. **Stamens** absent. **Gynoecium**, as in disc florets, but style and stigmas absent making the flower neuter.

(*b*) **Description of** ***Tridax procumbens*** (fig. 777) A weak decumbent perennial herb. **Leaves** simple, opposite, 1-3 inches long, toothed or lobed. **Inflorescence** a head, solitary, on long peduncle, heterogamous, consisting of



Compositae. FIG. 777 *Tridax procumbens* *A*, a branch with an inflorescence (head); *B*, a disc floret with a bracteole; *C*, corolla (split open) and epipetalous stamens; *D*, syngenesious stamens (split open); *E*, a ray floret; *F*, pistil and pappus; and *G*, a fruit (cypsela) with pappus (parachute mechanism).

pale yellow ray (ligulate) florets and deep yellow disc (tubular) florets. Involucre campanulate, bracts usually biseriate; receptacle slightly convex. *Disc florets*—regular, bisexual, tubular; bracteole thin, membranous, persistent. **Calyx** modified into feathery bristles (pappus). **Corolla** gamopetalous, tubular, 5-lobed, deep yellow. **Androecium**—stamens 5, syngenesious, epipetalous; anthers with short auricle. **Gynoecium**—carpels (2), syncarpous, style passing through the anther-cylinder (-tube); stigma 2-fid, hairy; ovary inferior, 1-celled, with one ovule. **Fruit** a cypsela, hairy, with bristly pappus. *Ray florets*—zygomorphic, unisexual, female, ligulate,

5-lobed; bracteole membranous, slightly coloured. **Calyx**, as in disc floret. **Corolla** gamopetalous, ligulate, pale yellow, 3-fid. **Gynoecium**—carpels (2), syncarpous; stigma 2-fid; ovary, as in disc florets. **Fruit**, as in disc florets.

(c) **Description of** *Sonchus asper* An annual weed, 2-3 ft. tall, with milky juice. **Stem** fistular, grooved **Leaves** radical (stalked), 6-10 inches long, and cauline (often semi-amplexicaul, i.e stem-clasping), toothed (spinous) or pinnatifid. **Inflorescence**—terminal heads in sub-corymbose or umbellate panicle, involucre ovoid, often thickened at the base; bracts multi-seriate, glabrous. **Flowers** homogamous, all ligulate, yellow; receptacle flat, naked. **Sepals** represented by pappus, multi-seriate, white, united at the base. **Petals** connate in a ligulate corolla, 5-toothed **Stamens** 5, syngenesious, epipetalous; anthers sagittate **Carpels** (2), syncarpous **Fruit** a cypsela, compressed, ribbed, with copious pappus

Family 15—*Apocynaceae* (1,400 sp.—84 sp. in India)

Habit—herbs, shrubs, trees, twiners and lianes; with latex, bicollateral bundles. **Leaves** simple, opposite or whorled, rarely alternate. **Flowers** regular, bisexual and hypogynous, in cymes, usually salver- or funnel-shaped, often with corona. **Calyx**—sepals (5), rarely (4), gamosepalous, imbricate. **Corolla**—petals (5), rarely (4), gamopetalous, twisted. **Androecium**—stamens 5, rarely 4, epipetalous, included within the corolla-tube; anthers usually connate around the stigma and apparently adnate to it. **Disc** present, ring-like or glandular. **Gynoecium**—carpels 2 or (2), apocarpous or syncarpous, superior. When apocarpous each ovary is 1-celled with marginal placentation, and when syncarpous the ovary may be 1-celled with parietal placentation, or 2-celled with axile placentation; ovules 2 - ∞ in each. **Fruit** a pair of follicles or berries or drupes. Seeds often with a crown of long silky hairs; mostly with endosperm. *Floral formula*—$K_{(5)}\overline{C_{(5)}A_5}\underline{G}_{(2)\text{ or }2}$.

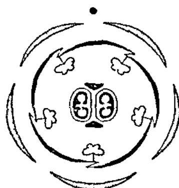
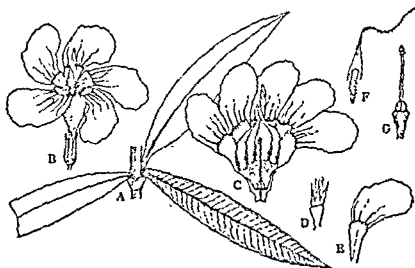


Fig. 778. Floral diagram of *Apocynaceae*.

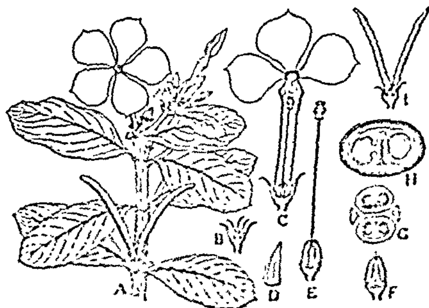
Examples. **Useful plants—medicinal**: *Rauwolfia serpentina* (B. CHANDRA OR SARPAGANDHA; H. & P. SARP GAND OR CHOTA CHAND), *Holarrhena antidysenterica* (B. KURCHI; H. KARCHI; P. KAWAR), *Wrightia tomentosa* (B. DUDH-KHOROI; H. DUDHI), yellow oleander (*Thevetia peruviana*; B. KALKE-PHUL; H. & P. PILA-KANER)—seeds very poisonous, devil tree (*Alstonia scholaris*; B. CHHATIM; H. CHATIUM; P. SATONA; **fruits**: *Carissa carandas* (B. KARANJA; H. & P. KARONDA)—a thorny shrub, and *Willughbeia* (B. LATA-AM); **ornamental**: herb—periwinkle (*Vinca rosea*; B. NAYANTARA; H. SADA-BAHAR): shrubs—oleander (*Nerium indicum*: B. KARAVI; H. & P.

KANER), *Ervatamia divaricata* (B. TAGAR ; H. & P. CHANDNI), pagoda or life tree (*Plumeria rubra* ; B. KAT-GOLAP ; H. GOLAINCHI) ; climbers—*Aganosma dichotoma* (B. MALATI ; H. MALTI),



Apocynaceae. FIG. 779. Oleander (*Nerium indicum*). *A*, a whorl of leaves; *B*, a flower; *C*, a flower opened out; *D*, calyx; *E*, a petal; *F*, a stamen (connective with hairy appendage); and *G*, pistil.

Vallaris solanacea (B. HAPAR-MALI ; H. HAMSAR), *Beaumontia grandiflora*, *Allamanda* and *Roupellia* ; tree—*Cerbera odollam*.



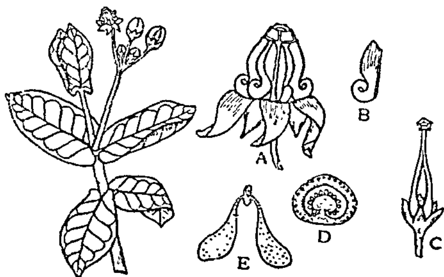
Apocynaceae. FIG. 780. Periwinkle (*Vinca rosea*). *A*, a branch; *B*, calyx; *C*, a flower split [illegible]; *D*, a stamen; *E*, pistil; *F*, [illegible]; *G*, [illegible]; *H*, [illegible]; and *I*, a pair of [illegible].

Other common plants of the family—*Ichnocarpus frutescens* (B. & H. DUDHI-LATA OF SHYAMALATA)—a climber, and *Rauwolfia canescens*—a shrub.

Description of Periwinkle Plant (*Vinca rosea*; fig. 780). An erect or procumbent herb or undershrub containing latex. Leaves opposite, 1½-2 inches lo [illegible] rs axillary, solitary, white or rosy, re[illegible] with distinct tube and limb Calyx—s[illegible] (5), connate, 5-lobed, with twisted [illegible], inserted within the corolla tube and [illegible] or absent. Disc of 2 large glands. G[illegible] aries but 1 style and 1 stigma, annulated. **Fruits** of 2 slender, erect follicles, 1 inch long.

Family 16—*Asclepiadaceae* (1,800 sp.—234 sp in India)

Habit—herbs, shrubs or twiners; with latex. **Leaves** opposite. **Flowers** regular, bisexual and hypogynous. **Calyx**—sepals (5), slightly connate at



Asclepiadaceae. FIG. 781. Madar (*Calotropis gigantea*). A branch (on the left); *A*, a flower; *B*, staminal corona with the filament (inner side); *C*, apocarpous pistil with the calyx at the base; *D*, section of ovary showing marginal placentation; and *E*, a pair of pollinia (see also fig. 248).

the base, odd sepal posterior. **Corolla**—petals (5), connate; aestivation commonly twisted, sometimes valvate. **Androecium**—stamens (5), connate in a hollow tube, with horn-like appendages known as the staminal corona, epipetalous; anthers coherent laterally and united with the style and the stigma forming a gynostegium; pollen cohering into two pollen masses known as the pollinia (sing. pollinium), one lying in each lateral anther lobe. **Gynoecium**—carpels two, free, superior; styles 2, free but united above forming a large dilated 5-angled stigma; stigma with five receptive surfaces lying on the underside or the edge of it; ovaries 2, free or united at the base only, each unilocular with many ovules in it; placentation marginal on a large intruding



Fig. 782. A pair of follicles of madar
Fig. 783. A hairy seed of the same.

ventral placenta. **Fruit** a pair of follicles, or by abortion only one. **Seeds** many, hairy. *Floral formula*—$K_{(5)}\ \overline{C_{(5)}\ [A_{(5)}}\ \underline{G}_{2}]$.

At each angle of the stigma there is a groove which secretes a sticky body called the corpusculum. The sticky secretion extends on either side into a connecting thread (retinaculum) to which each pollinium becomes attached.

Examples. **Useful plants—medicinal:** Indian sarsaparilla (*Hemidesmus indicus*; B. & H ANANTAMUL), *Tylophora asthmatica*, madar (*Calotropis gigantea* and *C procera*; B. AKANDA; H. &. P. AK)—also bast yields fibres and floss used for stuffing; **ornamental:** *Stephanotis*—a climber with white fragrant flowers, *Cryptostegia grandiflora*—a woody climber with large white flowers, *Pergularia*—an extensive twiner with small fragrant flowers.

Other common plants of the family—milk-weed or blood-flower (*Asclepias curassavica*)—an erect herb with orange-red flowers, *Sarcostemma* (B. SOM-LATA)—a shrub, *Hoya*—a thick-leaved epiphytic climber, *Dischidia nummularia*—a slender epiphytic climber, *D. rafflesiana* (see fig. 154)—an epiphytic climber, *Daemia extensa*—a foetid climbing under-shrub, *Dregea volubilis* (B. TITA-KUNGA)—a woody twiner with small greenish flowers, *Sarcolobus globosus* (B. BAOLI-LATA)—a large climber.

Family 17—*Convolvulaceae* (1,100 sp.—177 sp. in India)

Habit—mostly twiners. **Leaves** simple, alternate and exstipulate. **Inflorescence** cymose. **Flowers** regular, bisexual, hypogynous, often large and

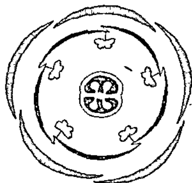


Fig. 784

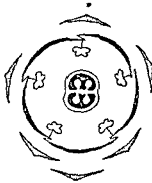


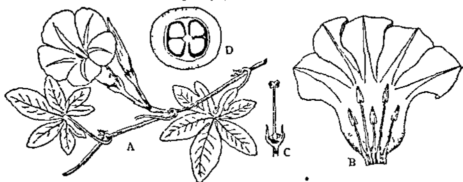
Fig. 785

Floral diagrams of *Convolvulaceae*. Fig. 784. *Ipomoea*. Fig. 785. Dodder (*Cuscuta*).

showy. **Sepals** 5, usually free, imbricate and persistent. **Petals** (5), united, funnel-shaped, twisted in bud, sometimes imbricate. **Stamens** 5, epipetalous, alternating with the petals. **Carpels** (2), rarely more, connate; ovary superior, with a disk at the base, *2-celled with 2 ovules in each cell*, or sometimes 4-celled with 1 ovule in each cell; placentation axile. **Fruit** a berry or a capsule. *Floral formula*—$K_5\ \overline{C_{(5)}\ A_5}\ \underline{G}_{(2)}$.

Examples. **Useful plants—vegetables:** sweet potato (*Batatas edulis*=*Ipomoea batatas*; B. MITHA-ALOO; H. & P. SHAKARKAND), and water bind-weed (*Ipomoea reptans*; B. & H KALMI-SAK; P. NALI); **medicinal:** *Ipomoea paniculata* (B. & H. BHUI KUMRA), *I. hederacea* (B. NIL-KALMI; H. KALA DANA) and Indian jalap (*Operculina turpethum*; B. TEORI; H. TARBUD); **ornamental:** morning glory (*I. purpurea*), railway creeper (*I. palmata*), moon flower (*I. grandiflora*), *I. pes tigridis* (B. LANGULI-LATA), *Quamoclit pinnata* (B. KUNJALATA or TORULATA; H. & P. KAMLATA), *Convolvulus* and elephant climber (*Argyreia speciosa*; B. SAMUDRA-SOK; H. SAMANDER PHEN).

Other common plants of the family—dodder (*Cuscuta* ; B. SWARNA-LATA ; H. AKASH-BEL ; P. AMARBEL—see fig. 65), bri (*Porana paniculata*) and *Evolvulus alsinoides*—a very commo weed with white flowers in grassy places



Convolvulaceae. FIG. 786. Railway creeper (*Ipomoea palmata*). *A*, a branch; *B*, a flower opened out; *C*, pistil; and *D*, section of ovary showing axile placentation

Family 18—*Solanaceae* (2,000 sp.—58 sp. in India)

Habit—herbs and shrubs. **Leaves** simple, sometimes pinnate, as in tomato, alternate. **Flowers** regular, bisexual, hypogynous. **Calyx**—sepals (5), united, persistent. **Corolla**—petals (5), united, usually funnel- or cup-shaped, 5-lobed, lobes valvate or twisted in bud. **Androecium**—stamens 5, epipetalous, alternating with the corolla-lobes; anthers apparently connate. **Gynoecium**—carpels (2), syncarpous; ovary superior; 2-celled or sometimes 4-celled owing to the development of false septum, as in tomato and thorn-apple, with many ovules in each; placentation axile. **Fruit** a berry or capsule with many seeds.

Floral formula—$K_{(5)} \overline{C_{(5)} A_5} G_{(2)}$.

Examples. **Useful plants—vegetables** : potato (*Solanum tuberosum*), brinjal (*S. melongena*), chilli or red pepper (*Capsicum frutescens* ; B. LANKA ; H. & P. LAL-MIRCH), and tomato (*Lycopersicum esculentum*) ; **medicinal** : deadly nightshade (*Atropa belladonna*), thorn-apple (*Datura fastuosa* ; B. DHUTRA ; H. & P. DHUTURA—fig. 788)—seeds very poisonous, henbane (*Hyoscyamus*), bittersweet (*Solanum dulcamara* ; B. & H. MITHA-BISH), *S. indicum* (B. BRIHATI ; H. BIRHATTA), *S. xanthocarpum* (B. KANTIKARI ; H. KATITA ; P. KANDIALI),

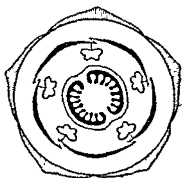
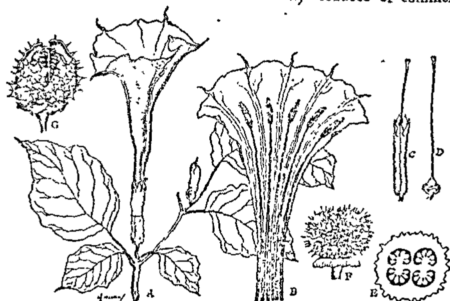


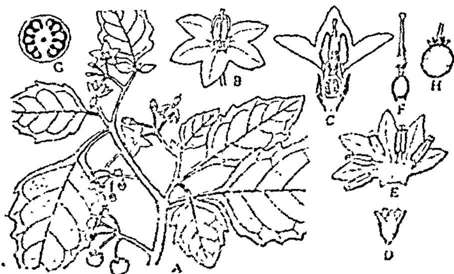
FIG. 787. Floral diagram of *Solanaceae*.

and *Withania somnifera* (B. ASWAGANDHA ; H. & P. ASGAND); **narcotic :** *tobacco* (*Nicotiana tabacum*)—tobacco of commerce



Solanaceae. FIG. 788. Thorn-apple (*Datura fastuosa*). *A*, a leafy branch with a flower; *B*, corolla (opened out) with epipetalous stamens; *C*, pistil and persistent calyx; *D*, pistil; *E*, section of ovary showing four chambers (chambers usually vary in number from 3 to 5); *F*, a young fruit; and *G*, a capsule.

and also a source of nicotine—an insecticide; **fruits**—gooseberry (*Physalis peruviana* ; B. TEPARI ; H. & P. RASBHARI) ; orna-



Solanaceae. FIG. 7[illegible]. Black nightshade (*Solanum nigrum*). *A*, a branch; *B*, a flower; *C*, a flower cut longitudinally; *D*, calyx; *E*, corolla with epipetalous stamens; *F*, pistil; *G*, ovary in transverse section showing axile placentation; and *H*, a fruit (berry).

mental: *Petunia*, queen of the night (*Cestrum nocturnum*; B. & H. HAS-NA-HANA), etc.

Other common plants of the family—black nightshade (*Solanum nigrum*; B. GURKI; H. GURKAMAI; P. MAKO—fig. 789), wild gooseberry (*Physalis minima*; B. BAN-TEPARI) and wild tobacco (*Nicotiana plumbaginifolia*).

Description of Black Nightshade Plant (*Solanum nigrum*; fig. 789). An annual weed. **Leaves** simple, alternate, entire or lobed, ovate-lanceolate; margin sinuate. **Inflorescence** an umbellate corymb, extra-axillary **Flowers** regular, bisexual, hypogynous, small, white in colour **Calyx**—sepals (5), gamosepalous, 5-toothed, persistent in the fruit. **Corolla**—petals (5), gamopetalous, *rotate, 5-lobed, lobes valvate in bud* **Androecium**—stamens 5, free, epipetalous; filaments short; anthers apparently united into a cone, dehiscing by terminal pores **Gynoecium**—carpels (2), syncarpous, ovary 2-celled, superior, with axile placentation, style bearded at base. **Fruit** a small, globose berry, black, sometimes red or yellow, with many seeds.

Family 19—*Scrophulariaceae* (2,600 sp.—273 sp. in India)

Habit—mostly herbs and undershrubs **Leaves** simple, alternate, opposite or whorled, exstipulate, sometimes showing heterophylly. **Inflorescence** commonly racemose (raceme or spike), sometimes cymose (dichasium), axillary or terminal, in some species flowers solitary. **Flowers** zygomorphic, 2-lipped, sometimes personate, but often showing a great diversity in form, bisexual, hypogynous; bracts and bracteoles generally present. **Calyx**—sepals (5), gamosepalous, 5-lobed, often imbricate. **Corolla**—petals (5), gamopetalous, often 2-lipped, sometimes spurred or saccate, medianly zygomorphic, very rarely regular as in *Scoparia*, imbricate. **Androecium**—*stamens 4, didynamous, sometimes 2*, arching over in pairs, posterior stamen absent or a staminode; anthers divaricate **Gynoecium**—carpels (2), syncarpous; ovary superior, bilocular, antero-posterior (and not oblique as in *Solanaceae*); *placentation axile*; *stigma*. numerous, sometimes few; disc ring-l sometimes unilateral. **Fruit**—commonly . usually numerous, minute, endospermic.

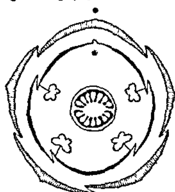


FIG. 790 Floral diagram of *Scrophulariaceae*.

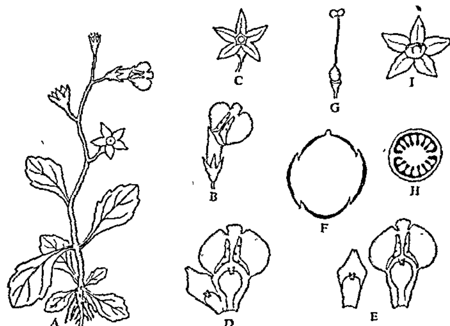
Examples. **Useful plants—medicinal:** foxglove (*Digitalis purpurea*), *Herpestis monnieria* (B. BRAHMI-SAK); **ornamental:** snapdragon (*Antirrhinum majus*), *Torenia fournieri*, *Russelia juncea*.

Other common plants of the family: weeds: *Mazus rugosus*, *Vandellia crustacea*, *V. pedunculata*, *V. multiflora*, *Bonnaya brachiata*, *Limnophila indica*, *L. heterophylla* showing heterophylly, *Hemiphragma heterophyllum* (in Shillong and Darjeeling) showing heterophylly, *Lindenbergia urticifolia* —a common weed growing on old walls, toad-flax (*Linaria ramosissima*), *Herpestis* sp. (=*Mecardonia dianthera*), *Scoparia dulcis*, *Veronica* sp., etc.

Family 20—*Acanthaceae* (2,000 sp.—514 sp. in India)

Habit—herbs, shrubs and a few climbers **Leaves** opposite. **Inflorescence** a spike or a cyme **Flowers** zygomorphic, often bilabiate, bisexual and hypogynous, often with conspicuous bracts and bracteoles. **Calyx**—sepals (4) or (5), united. **Corolla**—petals (4) or (5), connate in a two-

lipped or oblique corolla, twisted or imbricate in bud. **Androecium**—stamens 2 or 4, if 4 didynamous, epipetalous. **Gynoecium**—carpels (2), *syncarpous*; ovary 2-celled, superior, with 2 to many ovules in each cell; stigmas 2; placentation axile. **Fruit** a 2-valved capsule (see fig. 342). Seeds are in most cases supported on curved hooks (jaculators); these press the fruit



Scrophulariaceae. FIG. 791. *Mazus rugosus*. A, an entire plant—a small herb, B, a flower—bilabiate; C, calyx—gamosepalous and persistent; D, corolla split open with epipetalous, didynamous stamens arching over in pairs; E, corolla—the two lips separated, each with a pair of epipetalous stamens arching over; F, aestivation of corolla—imbricate; H, ovary in transection showing axile placentation; and I, fruit—capsule (dehiscing) with persistent calyx.

from inside, which bursts with a sudden jerk and scatters the seeds (see fig. 342). *Floral formula*—$K_{(4-5)}\ \overline{C_{(4-5)}\ A\ 2 \text{ or } 2+2}\ \underline{G}_{(2)}$.

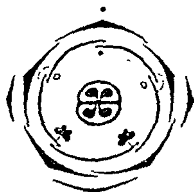


FIG. 792

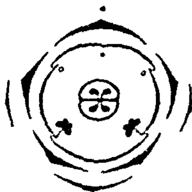
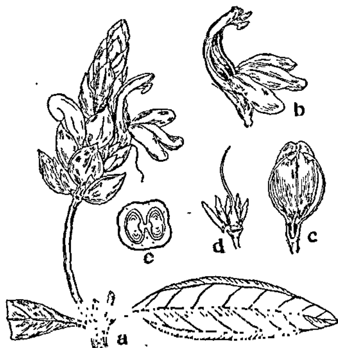


FIG. 793

FIGS. 792-3. Floral diagrams (two types) of *Acanthaceae*.

Examples. **Useful plants—medicinal:** *Andrographis paniculata* (B. KALMEGH; H. MAHATITA), and *Adhatoda vasica* (B. BASAK; H. ADALSA; P. BASUTI); **ornamental:** *Barleria prionitis* (B. KANTA-JHANTI; H. VAJRADANTI)—spinous, flowers yellow, *B. cristata* (B. JHANTI)—flowers white or rose-coloured, *B. strigosa*—flowers blue, *Meyenia erecta*—a pretty shrub with deep blue flowers, *Crossandra*—an undershrub with orange-coloured flowers, *Strobilanthes*, *Eranthemum* (= *Daedalacanthus*) *nervosus*—flowers bright blue, *Thunbergia grandiflora* (B. NIL-LATA)—a climber.

Other common plants of the family—herbs: *Acanthus ilicifolius* (B HARGOZA; H. HARKUCHKANTA), *Cardenthera triflora*—showing heterophylly (see fig. 176), *Hygrophila spinosa* (B KULEKHARA; H. GOKHULA-KANTA), *H. polysperma*—a common weed, *Ruellia tuberosa* (see fig 342), *R. prostrata*, *Phaylopsis*, *Rungia*, *Dicliptera* and *Ecbolium linneanum* (B NIL-KANTHA): climber: *Thunbergia alata*; shrubs. *Justicia gendarussa* (B JAGAT-MADAN) and several species of *Strobilanthes*.



Acanthaceae. FIG. 794. *Adhatoda vasica*. *a*, portion of a branch; *b*, a flower (bilabiate); *c*, stamens 2, adherent to the upper lip of the corolla; *d*, pistil (calyx opened out); and *e*, transverse section of ovary showing axile placentation.

Family 21—*Labiatae* (3,000 sp.—421 sp. in India)

Habit—herbs and shrubs with square stem. **Leaves** simple, opposite or whorled, exstipulate, with oil-glands. **Flowers** zygomorphic, bilabiate, hypogynous and bisexual. **Inflorescence** verticillaster (see p. 103); often reduced to true cyme, as in sacred basil (*Ocimum*; B. & H. TULSI). **Calyx**—sepals (5), gamosepalous, 5-lobed or 2-lipped, persistent. **Corolla**—petals (5), gamopetalous, bilabiate, i.e. 2-lipped; aestivation imbricate. **Androecium**—stamens 4, didynamous, sometimes only 2, as in

sage (*Salvia*; see fig. 295), epipetalous. **Gynoecium**—carpels (2), syncarpous; disc prominent; ovary 4-lobed and 4-celled, with one ovule in each cell, ascending from the base of the ovary; style gynobasic (see p. 130), i.e. develops from the depressed centre of the lobed ovary; stigma bifid. **Fruit**, a group of four nutlets, each with one seed. *Floral formula* $-K_{(5)}\overline{C_{(2+3)}A_{2+2}}\underline{G}_{(2)}$.

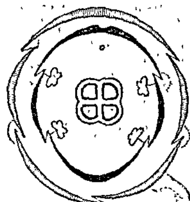
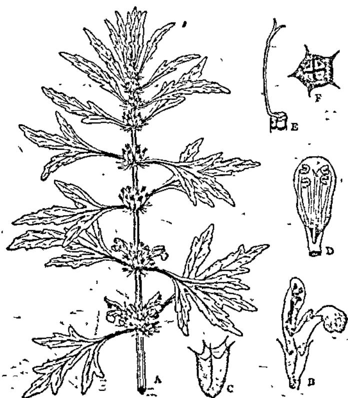


FIG. 795. Floral diagram of *Labiatae*.

Labiatae abounds in volatile, aromatic oils which are used in perfumery and also as stimulants. Many of them possess a bitter astringent principle.

... th inflores- ... calyx; D, ... gynobasic style; F, ovary with the disc in longitudinal section; and G, fruit of four nutlets enclosed in the persistent calyx.

Examples. **Useful plants—medicinal**: sacred basil (*Ocimum sanctum*; B., H. & P. TULSI), mint (*Mentha arvensis*; B. PUDINA; H. PODINA), peppermint (M. *piperita*)—yields peppermint oil from which menthol is obtained, thyme (*Thymus*)—yields thyme oil from which thymol is obtained, patchouli (*Pogostemon*)—yields patchouli oil, and rosemary (*Rosmarinus*)—yields oil of rosemary; **ornamental**: sage (*Salvia plebeja* and *S. coccinea*; B. BHUI-TULSI; P. TUKHMALANGA), country borage (*Coleus aromaticus*; B. & H. PATHUR-CHUR—see fig. 33) and marjoram (*Origanum vulgare*)—cultivated for its scented leaves.



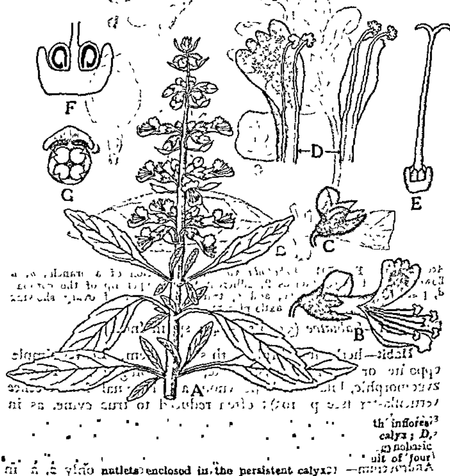
Labiatae. FIG. 797. *Leo*
and inflorescences; *B*, a
mous and epipetalous; *E*,
and *F*, fruit of four nutlets enclosed in persistent calyx.

Other common plants of the family—*Ocimum gratissimum* (B. & H. RAM-TULSI), *basil* (O. *basilicum*; B. & H. BABUI-TULSI; P. BABURI OF NIAZBO), wild basil (O. *canum*; B. & H. BAN-TULSI), *Anisomeles indica* (B. GOBRA), *Leonurus sibiricus* (B. DRONA; H. HALKUSHA OF GUMA), *Leucas linifolia* and *L. aspera* (B. SWET-DRONA; H. CHOTA-HALKUSHA) and *Dysophylla*—marsh herbs.

sage (*Salvia*; see fig. 295); epipetalous. **Gynoecium**—carpels (2), syncarpous; disc prominent; ovary 4-lobed and 4-celled, with one ovule in each cell, ascending from the base of the ovary; style gynobasic (see p. 130), i.e. develops from the depressed centre of the lobed ovary; stigma bifid. **Fruit** a group of four nutlets, each with one seed. *Floral formula* —$K_{(5)}\ \overline{C_{(2+3)}A_{2+2}}\ \underline{G}_{(2)}$.

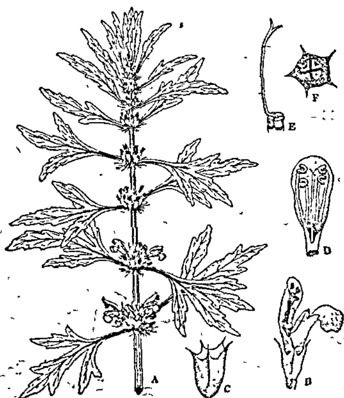
FIG. 795. Floral diagram of *Labiatae*.

Labiatae abounds in volatile, aromatic oils which are used in perfumery and also as stimulants. Many of them possess a bitter astringent principle.



th inflores-
calyx; D,
gynobasic
uit of four
nutlets enclosed in the persistent calyx.

Examples. **Useful plants—medicinal**: sacred basil (*Ocimum sanctum:* B., H. & P. TULSI), mint (*Mentha arvensis*, B. PUDINA; H. PODINA), peppermint (*M. piperita*)—yields peppermint oil from which menthol is obtained, thyme (*Thymus*)—yields thyme oil from which thymol is obtained, patchouli (*Pogostemon*)—yields patchouli oil, and rosemary (*Rosmarinus*)—yields oil of rosemary; **ornamental**: sage (*Salvia plebeja* and *S. coccinea*; B. BHUI-TULSI; P. TUKHMALANGA), country borage (*Coleus aromaticus*; B. & H. PATHUR-CHUR—see fig. 33) and marjoram (*Origanum vulgare*)—cultivated for its scented leaves.



Labiatae. FIG. 797. *Leonurus sibiricus.* *A*, a branch with opposite leaves and inflorescences; *B*, a flower (bilabiate); *C*, calyx; *D*, stamens—didynamous and epipetalous; *E*, pistil (note the gynobasic style and 4-lobed ovary); and *F*, fruit of four nutlets enclosed in persistent calyx.

Other common plants of the family—*Ocimum gratissimum* (B. & H. RAM-TULSI), *basil* (*O. basilicum*; B. & H. BABUI-TULSI; P. BABURI or NIAZBO), wild basil (*O. canum*; B. & H. BAN-TULSI), *Anisomeles indica* (B. GOBRA), *Leonurus sibiricus* (B. DRONA; H. HALKUSHA or GUMA), *Leucas linifolia* and *L. aspera* (B. SWET-DRONA; H. CHOTA-HALKUSHA) and *Dysophylla*—marsh herbs.

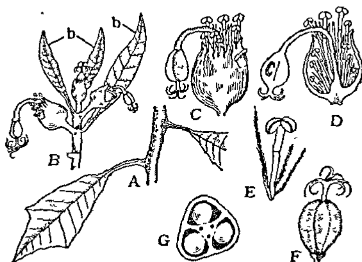
. 797). An erect annual weed.
,ite-decussate, deeply lobed In-
», bisexual, hypogynous, reddish;
5 toothed, unequal, teeth spines-
e, 2-lipped, upper lip entire and
lidynamous; conniving. Gynoecium—carpels (2), syncarpous; ovary 4-lobed; style gynobasic; stigma 2-fid. **Fruit** of 4 dry nutlets.

Description of Sage Plant (*Salvia plebeja*; see fig. 295). An annual erect herb, ½ - 2 ft. high. **Leaves** simple, opposite, ovate. **Inflorescence** racemose (panicled); bracts—the lower leaf-like and the upper small and lanceolate. **Flowers** small, about ⅛ inch, bluish, bisexual, hypogynous, bilabiate. **Calyx**—sepals (5), gamosepalous, 2-lipped, upper lip entire or 2-toothed, lower 3-fid **Corolla**—petals (5), gamopetalous, bilabiate, upper lip entire and lower lip 3-lobed, lateral lobes spreading; corolla-tube with a ring of hairs inside. **Androecium**—stamens 2, perfect; filament articulated to an elongated, curved connective widely separating the two anther lobes, the upper lobe fertile bearing pollen grains and the lower lobe sterile. Disc usually enlarged in front. **Gynoecium**—carpels (2), syncarpous; style long, gynobasic; *stigma* bifid; ovary 4-lobed. **Fruit** a group of 4 nutlets.

SUB-CLASS III. MONOCHLAMYDEAE

Family 22—*Euphorbiaceae* (4,000 sp.—444 sp. in India)

Habit—herbs, shrubs and trees, often with acrid milky juice. **Leaves** simple, usually alternate; *stipules* usually present. **Inflorescence** varying—racemose or cymose, or mixed, or



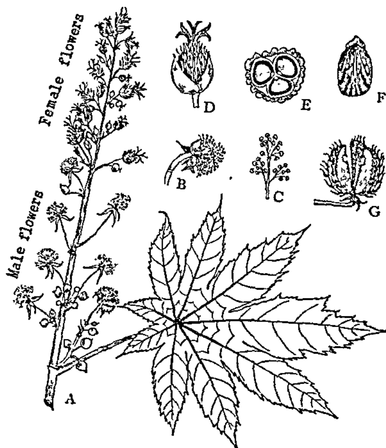
(reduced to a stamen only) with bract and bracteoles at the base; F, female flower (reduced to a pistil only); G, ovary in transverse section.

a cyathium (see p. 102), as in spurge (*Euphorbia*; B. & H. SIJ) and jew's slipper (*Pedilanthus*; B. RANG-CHITA; H. NAG-DAMAN).

Flowers small, bracteate, regular, hypogynous, always unisexual, monoecious or dioecious; rudiments of the other sex are sometimes present. **Perianth** in 1 or 2 whorls, sometimes absent, dissimilar in male and female flowers.

Male Flowers: in spurges (*Euphorbia*) and jew's slipper (*Pedilanthus*) flowers are reduced to solitary stamens without any perianth (see p. 102); in other cases stamens usually many or sometimes few; filaments either free or connate in 1 to many bundles. *Floral formula*—$P_{0 \text{ or } 5}\ A_{1-\infty}\ G_0$.

Female Flowers: **carpels** (3), syncarpous; ovary 3-celled, 3-lobed, superior, with 1 or 2 ovules in each loculus, pendulous; styles 3, each bifid; stigmas 6. **Fruit** mostly a capsule or a regma. *Floral formula*—$P_{0 \text{ or } 5}\ A_0\ \underline{G}_{(3)}$.



Euphorbiaceae. FIG. 799. Castor (*Ricinus communis*). *A*, a branch with a leaf and an inflorescence; *B*, a male flower; *C*, branched stamens; *D*, a female flower; *E*, ovary in transverse section; *F*, a seed; and *G*, a fruit (regma) splitting.

Examples. **Useful plants**—castor (*Ricinus communis*; fig. 799)—seeds yield castor oil, *Croton tiglium* (B. JAIPAL ; H. & P. JAMOLGOTA)—seeds yield croton oil, *Aleurites*—a few species are cultivated in India for TUNG oil, Indian walnut (*A. moluccana* ; B. DESHI-AKROT), *Baccaurea* (B. LATKAN ; H. LUTKO)—aril pulpy and edible, emblic myrobalan (*Phyllanthus emblica* ; B. AMLA ; H. AMLIKA)—fruits edible, rich in vitamins, medicinal and also used for tanning, *P. acidus* (B. NOAR ; H. CHALMERI)—fruits edible, sour but tasteful, tapioca (*Manihot utilissima*)—tuberous roots yield a valuable starchy food (tapioca), *M. glaziovii*—yields ceara rubber, *Hevea brasiliensis*—yields para rubber; **ornamental**: garden crotons (*Codiaeum variegatum* : B. PATA-BAHAR) with variegated leaves, poinsettia (*Euphorbia pulcherrima* ; B. LAL-PATA—fig. 798), *Bischofia* and *Bridelia* are timber trees, and child life tree (*Putranjiva roxburghii* ; B. JIA-PUTI)—an evergreen shade tree.

Other common plants of the family—spurges (*Euphorbia*) with about 750 species, e.g. *E. antiquorum* (B. BAJ-BARAN or TESHIRA-MANSHA), *E. nerifolia* (B. MANSHA-SIJ ; H. SIJ ; P. GANGICHU), *E. nivulia* (B. SIJ ; H. & P. SIJ or THOR), *E. pilulifera* (B. KERUI ; H. DUDHI ; P. DODAK), *E. heterophylla*—an annual herb, *E. thymifolia*—a weed, *E. royleana*—stem succulent and angular, jew's slipper (*Pedilanthus tithymaloides* ; B. RANG-CHITA ; H. NAG-DAMAN), *Croton sparsiflorus*, *Phyllanthus niruri* (B. BHUI-AMLA) and *Acalypha indica* (B. MUKTO-JHURI ; H. KUPPI) are common weeds, nettle (*Tragia involucrata* ; B. BICHUTI ; H. & P. BARHANTA)—a twiner with stinging hairs, *Jatropha gossypifolia* (B. & H. LAL-BHARENDA), physic or purging nut (*J. curcas* ; B. BAGH-BHARENDA ; H. BAGH-BHARENDA or JANGLI-ARANDI), *Chrozophora*—a common weed, *Breynia rhamnoides* (B. SITKI)—a shrub, and *Trewia nudiflora* (B. PITULI ; H. BHILLAURA)—a tree.

Description of Castor Plant (*Ricinus communis*; fig. 799). *An evergreen*, much-branched, tall shrub. **Leaves** simple, alternate, broad, palmately lobed and veined, lobes usually 7 or 9. **Inflorescence** a terminal raceme (sub-panicled). **Flowers** unisexual, monoecious, apetalous, *upper female and lower male*. *Male flowers*: **calyx** membranous, splitting *into 3-5 segments*. **Corolla** absent. **Androecium**—*stamens many*, united into several bundles (polyadelphous); anther-lobes divergent. *Female flowers*: **calyx** gamosepalous, spathaceous, caducous. **Corolla** absent. **Gynoecium**—carpels (3), connate; ovary 3-lobed and *3-celled*, with a single ovule in each cell; styles long or *short*, *3*, each 2-fid; stigmas 6. **Fruit** a *regma*, ½-1 inch in length, splitting into three cocci, each 2-valved. **Seeds** albuminous, one in each coccus.

CHAPTER IV

SELECTED FAMILIES OF MONOCOTYLEDONS

SUB-CLASS I. PETALOIDEAE

Family 1—*Liliaceae* (2,600 sp.)

Habit—herbs, rarely shrubs, with fibrous roots, or bulb or corm or creeping rootstock. **Leaves** simple, radical or cauline or both. **Flowers** regular, bisexual and hypogynous, solitary or in spike, raceme or panicle ; bracts small, scarious (thin and dry) or spathaceous. **Perianth** petaloid, usually 6 segments in two whorls, usually free (polyphyllous), sometimes united (gamophyllous). **Androecium**—stamens 6, in two whorls, rarely 3, hypogynous, free, or united with the perianth (epiphyllous). **Gynoecium**—carpels (3), syncarpous ; ovary superior, 3-celled ; ovules 2 or more in each loculus ; placentation axile ; stigmas usually 3. **Fruit** a berry or capsule. Seeds albuminous. *Floral formula*—$P_{3+3}\,A_{3+3}\,\underline{G}_{(3)}$ *or* $\overline{P_{(3+3)}A}_{3+3}\,\underline{G}_{(3)}$.

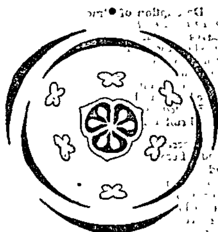
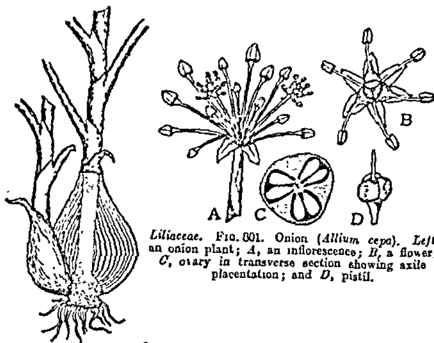


Fig. 800. Floral diagram of *Liliaceae*.

Examples. **Useful plants—vegetables**: onion (*Allium cepa*), garlic (*A. sativum*), shallot (*A. ascalonicum*), leek (*A. tuberosum*), etc. ; **medicinal**: *Asparagus racemosus* (B. SATAMULI ; H. & P. SATAWAR), sarsaparilla (*Smilax macrophylla* ; B. KUMARIKA ; H. CHOBCHINI ; P. USHBA), Indian aloe (*Aloe vera* ; B. GHRITA-KUMARI ; H. GHIKAVAR), meadow saffron (*Colchicum luteum*), asphodel (*Asphodelus*), etc. ; **ornamental**: lily (*Lilium*) with about 60 sp., glory lily (*Gloriosa superba* ; B. ULAT-CHANDAL; H. KALIARI; P. KULHARI), day lily (*Hemerocallis*), dagger plant or Adam's needle (*Yucca*), dragon plant (*Dracaena*), *Sansevieria lourentii*—green foliage with yellow stripes, and *Scilla* indica—leaf-tip reaching the ground develops adven-

titious bud; fibre-yielding: *Phormium*—yielding New Zealand flax, and bowstring hemp *Sanseviera roxburghiana*; B. MURVA; H. MARUL).



Liliaceae. FIG. 801. Onion (*Allium cepa*). *Left*, an onion plant; *A*, an inflorescence; *B*, a flower; *C*, ovary in transverse section showing axile placentation; and *D*, pistil.

Description of Onion Plant (*Allium cepa*; fig. 801). A cultivated herb with tunicated bulb. Bulb surrounded by inner fleshy and outer dry scales. **Leaves** radical, cylindrical, hollow, sheathing. **Inflorescence** a terminal umbel on the leafless flowering stem or scape. Bracts 2, sometimes 3, membranous, enclosing the young umbel. **Flowers** small, white, regular, bisexual, hypogynous, sometimes replaced by bulbils. **Perianth** of 6 lobes, connate below, campanulate. **Androecium**—stamens 6, free; filaments narrow or dilated at the base. **Gynoecium**—carpels (3), syncarpous; ovary 3-lobed and 3-celled; style short, filiform; stigma minute; ovules usually 2 in each cell. **Fruit** a membraneous capsule.

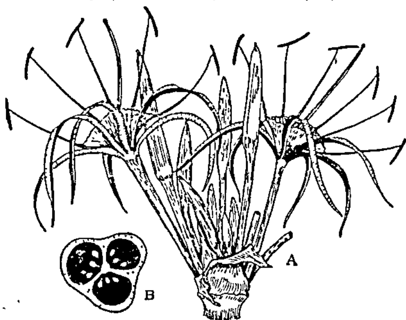
Description of Asphodel Plant (*Asphodelus tenuifolius*). An annual weed. **Leaves** radical, slender, erect, semi-terete, fistular, 6-12 inches long and $\frac{1}{12}$ inch in diameter. **Scapes** several, 1½-3 ft. long, ending in a laxly racemose inflorescence. **Bracts** scarious. **Flowers** small, regular, bisexual, hypogynous. **Perianth** of six segments, white, each with a brownish costa, ¼ inch long, free or united at the base, marcescent. **Androecium**—*stamens* 6, shorter than the perianth; filaments flattened at the base enclosing the ovary; anthers versatile. **Gynoecium**—*carpels* (3), syncarpous, ovary 3-celled, with two ovules in each; stigma 3-lobed. **Fruit** a capsule, ⅛ inch long, broader in diameter, usually with one seed in each cell. **Seed** albuminous.

Family 2—*Amaryllidaceae* (950 sp.)

It has the same general characters as *Liliaceae*, but it differs from the latter in its ovary being inferior.

Examples: easter lily (*Amaryllis*), eucharis lily (*Eucharis*),

pin-cushion lily (*Haemanthus*), spider lily (*Pancratium*; fig. 802), zephyr lily (*Zephyranthes*), tuberose (*Polyanthes tube-*

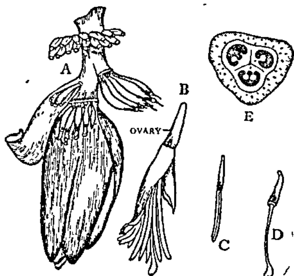


Amaryllidaceae. FIG. 802. Spider lily (*Pancratium*) *A*, inflorescence; and *B*, ovary in transverse section showing axile placentation.

rosa; B. RAJANI-GANDHA; H. & P. GUL-SHABO), American aloe or century plant (*Agave americana*), *Curculigo orchioides* (B. TALMULI; H. MUSLIKAND), daffodil (*Narcissus*), *Crinum asiaticum* (B. SUKH-DARSHAN), and *C. latifolium*.

Family 3—*Scitamineae* (1,180 sp.)

Habit—herbs (rarely woody and tree-like, e.g. traveller's tree); underground stem usually in the form of a slender or stout rhizome; aerial stem distinct or 'false' made of

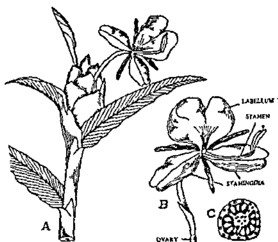


Musaceae. FIG. 803. Banana (*Musa paradisiaca*). *A*, spadix; *B*, a flower; *C*, a stamen; *D*, pistil; and E, ovary in transection showing axile placentation (section taken from a wild variety).

sheathing leaf-bases, and the flowering stem or scape pushing out through the 'false' stem and ending in an inflorescence. **Inflorescence** a raceme, spike or spadix with often large spathes, either terminal or axillary. **Flowers** zygomorphic, mostly bisexual and epigynous; bracts often spathaceous. **Perianth** of six segments in two whorls. **Androecium**—stamens varying (see sub-families). **Gynoecium**—carpels (3), syncarpous; ovary inferior and trilocular; placentation axile; ovules usually many. **Fruit** a berry or capsule. **Seeds** with perisperm, sometimes with aril or with endosperm. This family has been divided into three sub-families, mainly depending on the number of stamens.

(1) *Musaceae* (150 sp.). **Perianth** petaloid in two series—one with 5 limbs united and another solitary and free. **Stamens** in 2 whorls, 5 perfect and the 6th one sterile or absent. *Floral formula*—$P_{5+1}\ A_{3+2}\ \bar{G}_{(3)}$.

Examples: banana (*Musa paradisiaca*)—a dessert fruit, plantain (*M. sapientum*)—green fruit used as a vegetable, dwarf plantain of Assam (*M. sanguinea*)—fruit not edible, *M. superba* and *M. nepalensis* — ornamental, fruits not edible, *M. textilis* yielding Manila hemp of commerce, and traveller's tree (*Ravenala*; B. PANTHA-PADAP—see fig. 171).

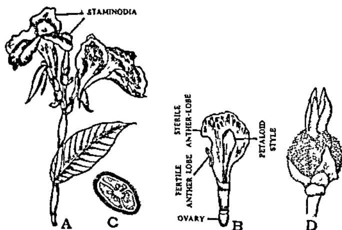


Zingiberaceae. FIG. 804. Butterfly lily (*Hedychium coronarium*). *A*, a branch with inflorescence; *B*, a flower; and *C*, ovary in tran section showing axile placentation.

(2) *Zingiberaceae* (800 sp.). **Perianth** of 6 segments in 2 whorls, generally distinguishable into calyx and corolla. **Stamens** in 2 whorls —only 1 perfect and epipetalous (this is the posterior one of the inner whorl), the other 2 stamens of this whorl are united to form a 2-lipped labellum; the anterior stamen of the outer whorl is absent and the remaining 2 modified into petaloid staminodes or absent. **Style** slender, passing through the two anther-lobes. *Floral formula*—$K_{(3)}\ C_{3}A_{1}\ \bar{G}_{(3)}$.

Examples: ginger (*Zingiber officinale*), wild ginger (*Z. casumunar*), turmeric (*Curcuma domestica*), wild turmeric (*C. aromatica*), mango ginger (*C. amada* ; B. AMADA ; H. AM-HALDI), butterfly lily (*Hedychium coronarium* ; B. DULAL-CHAMPA), *Kaempferia rotunda* (B. BHUI-CHAMPA), *Costus*, *Alpinia allughas* (B. TARA), *A. galanga* (B. & H. KULANJAN)—medicinal, *Globba bulbifera* (see fig. 510), cardamom (*Elettaria cardamomum* ; B. CHHOTA-ELAICH) *Amomum subulatum* (B. BARA-ELAICH), *A. aromaticum* (B. MORAN-HANCHI).

(3) *Cannaceae* (60 sp.). **Perianth** in 2 whorls of 3 members each—the outer 3 (sepals) free and the inner 3 (petals)



Cannaceae. FIG. 805. Indian shot (*Canna indica*). *A*, a branch; *B*, a flower (perianth and staminodia cut out); *C*, ovary in transection showing axile placentation; and *D*, a fruit.

united. **Stamens** in 2 whorls—only 1 anther-lobe of 1 stamen (posterior) fertile, the other anther-lobe together with the filament becoming petaloid ; one stamen is suppressed and the other stamens modified into petaloid staminodes, one of which forms the labellum covering the style. All petaloid staminodes together with the petaloid anther-lobe are united below with the corolla into a cylindrical tube. **Style** petaloid and flattened. *Floral formula*—$K_3 C_{(3)} A_{\frac{1}{2}} \overline{G}_{(3)}$.

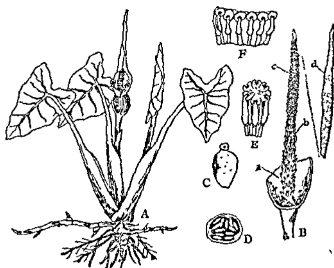
Examples: *Canna* (50 sp.), e.g. Indian shot (*Canna indica* ; B. SARBAJAYA), *Clinogyne dichotoma* (B. SHITAL-PATI), arrowroot (*Maranta arundinacea*) and *Phrynium*.

SUB-CLASS II. SPADICIFLORAE

Family 4—*Araceae* (1,900 sp.)

Habit—herbs, or occasionally climbing shrubs with two kinds of aerial roots—clinging roots fixing the plant to its support and hanging roots ulti-

mately growing down into the soil; with an acrid juice or latex which is in some cases poisonous. Stem in the form of rhizome or corm. Plants of this family grow in moist, shady places. **Leaves** are alternate, radical, simple or compound; in climbing species cauline leaves distinctly alternate, often broad, long-petioled and palmately veined (reticulate). **Inflorescence** in the form of spadix subtended by a large, often brightly coloured spathe; usually monoecious with female flowers at the base, higher up some neuter flowers in some species and above them a number of closely-packed male flowers; the axis of the spadix is prolonged into a sterile appendix. **Flowers** sessile, naked and unisexual (monoecious or dioecious) or sometimes bisexual. **Perianth** absent or of 6 scales. **Androecium**—stamens ∞ or reduced to 6-10 or even to 1, filaments very short, often united into a *synandrium*; anthers 2-celled, often dehiscing by terminal pore. **Gynoecium**—carpels, (1-3), connate; ovary 1- to 3-celled, superior; each cell with 1 or more



Araceae. Fig. 806. Taro (*Colocasia esculenta*). *A*, a plant; *B*, an inflorescence (spadix)—*a*, female flowers; *b*, neuter flowers; *c*, male flowers; and *d*, appendix; *C*, pistil; *D*, section of ovary; *E*, synandrium; and *F*, synandrium opened out.

ovules; placentation often parietal. **Fruit** a berry. **Seed** with or without endosperm. Flowers are protogynous and pollination is mainly effected by insects. Appendix in many species with strong, offensive smell. *Floral formula*— $P_0 A_{\infty \text{ or } 6-10 \text{ or } 1} \underline{G}_{(1-3)}$.

Examples: taro (*Colocasia* ...
Alocasia indica (B. MAN-KACHU; ...
lobatum (B. GHET-KACHU), trum...
phallus campanulatus (B. OL; H...
(*Arum maculatum*), snake plant (...
calamus; B. LOCH; H. & P. WACH...
H. & P. JAL-KHUMBI—see fig. ...
scandens—a climber, and *Monste*...
shrubs.

Family 5—*Palmaceae* (1,500 sp.)

Habit—shrubs or trees, sometimes climbing, e.g. cane (*Calamus*). Stem erect, unbranched and woody, rarely branched, e.g. *Hyphaene*. **Roots** numerous, adventitious (fibrous) deve-

loping from the base of the stem. **Leaves** usually forming a crown, plaited in bud, sometimes very large (in some species 50 ft. long and 8 ft. wide); these are of two types—palmately cut or divided (**fan palms**) or pinnately cut or divided (**feather palms**); petiole often with sheathing base. **Flowers** sessile, small and inconspicuous but produced in immense numbers presenting an imposing appearance (date-palm bears about 12,000 male flowers and *Metroxylon* about 624,000 flowers), regular, hypogynous, unisexual or bisexual, in simple or compound spadix enclosed in one or more sheathing spathes; male and female flowers in the same inflorescence or in two, either monoecious or dioecious. **Perianth** in two series, 3+3, the outer being often smaller, imbricate and persistent in the female flower. **Androecium**—stamens usually in two series, 3+3; filaments free or connate; anthers versatile, 2-celled. Rudiment of the pistil sometimes present in the male flower. **Gynoecium**—carpels (3) or 3, syncarpous or apocarpous; ovary superior, unilocular or trilocular, with 1 or 3 ovules. **Fruit** a drupe, berry or nut. **Seed** albuminous. Pollination by wind; pollen produced in huge quantities. Some palms are pollinated by insects also. Flowers protandrous, and hence self-pollination is prevented. *Floral formula—male flower:* $P_{3+3}A_{3+3}G_0$, and *female flower:* $P_{3+3}A_0\underline{G}_{(3)\text{ or }3}$.

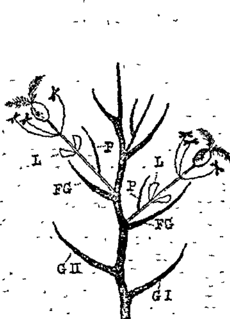
Economically it is one of the most important families as many of the most useful products are obtained from several species of this family. Many palms such as palmyra-palm, toddy-palm, date-palm, coconut-palm, etc., are tapped for toddy (fermented country liquor) or for sweet juice from which jaggery or sugar is made. Coconut-palm, date-palm, palmyra-palm, etc., yield edible fruits. Strong fibres are obtained from some palms, which are used for making mats, mattresses and brushes, and also for stuffing cushions. Leaves of many palms are woven into mats, hats and baskets and also used for thatching. Some palms yield oil, e.g. coconut-palm, oil-palm, etc. Sago-palms (*Metroxylon* and *Caryota*) yield sago, which is obtained by crushing the pith. Betel-nut is used for masticating with betel leaf. Endosperm of vegetable ivory-palm is very hard and made into billiard balls. Cane is used for making chairs, sofas, tables, and baskets and also used for a variety of other purposes. Many palms are ornamental, e.g. fan palms: *Livistonia, Licuala, Sabal, Prichardia grandis*—a very beautiful palm; and feather palms: cabbage-palm (*Areca oleracea*), sugar-palm (*Arenga saccharifera*), bottle-palm (*Oreodoxa regia*), *Pinanga*, dwarf cane (*Calamus ciliaris*), etc.

Examples. **Fan-palms**: palmyra-palm (*Borassus flabellifer*), talipot-palm (*Corypha*—grows to a height of about 80 ft., flowers once after about 150 years and then dies), double coconut-palm (*Lodoicea*—native of Seychelles Islands—bears the largest known seed and fruit; the latter sometimes measuring about 4 ft.), oil-palm (*Elaeis guinensis*) and *Hyphaene*—showing dichotomous branching. **Feather-palms**: Indian sago-palm or fishtail-palm or toddy-palm (*Caryota urens*), coconut-palm (*Cocos nucifera*), edible date-palm (*Phoenix dactylifera*), wild date-palm (*P. sylvestris*), betelnut-palm (*Areca catechu*), cane (*Calamus*), sago-palm (*Metroxylon rumphii*), nipa-palm (*Nipa fruticans*; B. GOLPATA—a stemless palm), vegetable ivory-palm (*Phytelephas*), and *Zalacca beccarii*—its large cane-like fruits are sold at Shillong market.

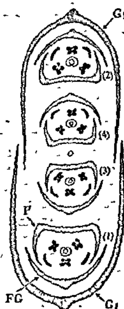
SUB-CLASS III. GLUMIFLORAE

Family 6—*Graminaceae* (5,000 sp.)

Habit—herbs, rarely woody, as bamboos. **Stem** cylindrical with distinct nodes and internodes (sometimes hollow). **Leaves**



Graminaceae. FIG. 807. Spikelet of a grass. *G* I, first empty glume; *G* II, second empty glume; *FG*, flowering glume; *P*, palea; *L*, lodicule; stamens and carpel are evident in the figure.



Graminaceae. FIG. 808. Floral diagram of a spikelet of a grass. *G* I, first empty glume; *G* II, second empty glume; *FG*, flowering glume; *P*, palea; (1), (2), (3) and (4) are florets of the spikelet.

simple, alternate, distichous, with sheathing leaf-base which is split open on the side opposite to the leaf-blade ; there is a hairy structure at the base of the leaf-blade, called the ligule. **Inflorescence** usually a spike or a panicle of spikelets (figs. 807-8) ; each spikelet consists of one, few or many flowers, and bears at the base three bracts or glumes, one placed a little above the other ; the lowest two are empty and the third one flowering (called *lemma*), i.e. it encloses a flower in its axil ; opposite to the flowering glume (or *lemma*) there is a somewhat smaller, 2-nerved glume, known as the palea. The spikelet may be sessile or stalked. **Flowers** usually bisexual, sometimes unisexual, monoecious. **Perianth** represented by two minute scales at the base of the flower, called the lodicules ; these are regarded as forming the rudimentary perianth. **Androecium**—stamens 3, sometimes 6, as in rice and bamboo ; anthers versatile and pendulous. **Gynoecium**—carpel 1 ; ovary superior, 1-celled, with 1 ovule ; stigmas 2, feathery. **Fruit** caryopsis. Seed albuminous. Pollination is brought about by wind. *Floral formula*—$P_{\text{lodicules or } 0}\, A_{3 \text{ or } 6}\, \underline{G}_1$.

From an economic standpoint *Graminaceae* is regarded as the most important family as cereals and millets which con-

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squarrosus (B. & H. BENA or KHUS-KHUS)—roots are woven into summer screen (KHUS-KHUS), sabai grass (*Ischaemum angustifolium*)—paper is manufactured from this grass, etc.

Other common plants of the family—dog grass (*Cynodon dactylon* ; B. DURBA-GHAS ; H. & P. DOOB), love thorn (*Chrysopogon aciculatus* ; B. CHOR-KANTA), *Imperata cylindrica* (B. ULU), Panicum *crus-galli* (B. SHYAMA), etc.

(a) **Description of Rice Plant** (*Oryza sativa*; fig. 809). A tall annual grass. Leaves simple, long, narrow and flat, with sheathing base and ligule.

Graminaceae. FIG. 809. Rice (*Oryza sativa*). *A*, portion of a branch with sheathing leaves and ligules; *B*, a panicle of spikelets; *C*, 1-flowered spikelet (note the glumes and stamens); *D*, spikelet dissected out—*G* I, first empty glume; *G* II, second empty glume; *FG*, flowering glume; *P*, palea; *L*, lodicules; *S S*, stamens; and *G*, gynoecium.

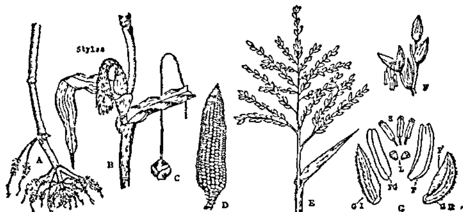
Inflorescence a panicle of spikelets; spikelets 1-flowered, articulated to slender branches of the panicle. Flowers bisexual. Glumes I and II minute, *empty*; glume III hard, keeled, 5-veined, awnless or with a short or long terminal awn (a bristle-like appendage); palea as long as glume *III*, keeled, 3-nerved. Enclosed in glume III and palea there is a flower. Perianth is represented by 2, entire or 2-lobed, minute bodies known as lodicules. [illegible] ecium—carpel 1; [illegible] n is known as [illegible] III and palea. [illegible] na with distinct [illegible] g. 15). Pollina- [illegible] ltivated for the sake of the grain which is rich in starch.

(b) **Description of Maize Plant** (*Zea mays*; fig. 810). Maize or Indian corn plant is a tall, stout, annual grass cultivated during the rainy season. The plant is monoecious, bearing male and female spikelets in separate [illegible]

[illegible] spadix remains enclosed in a number of spathes.

Male Spikelets : they occur in pairs—one sessile and the other stalked; each spikelet is 2 flowered. **Glumes**—4, acute; I and II distinctly nerved and empty; glume I encloses glume III (flowering glume) and glume IV (palea), which are hyaline. Enclosed in glumes III and IV there is a flower. **Perianth** is represented by two small fleshy cup-shaped bodies, known as lodicules. **Androecium**—stamens 3; anthers linear and pendulous. Similarly glume II encloses a flowering glume and a palea with another flower inside.

Female Spikelets : spikelets are densely crowded in several vertical rows on the fleshy rachis and are sessile. Each spikelet with a lower barren (extremely reduced) floret and an upper fertile (normal) one. Glumes—4, membranous; glumes I and II very broad and empty; glume III hyaline and paleate; and glume IV (palea) hyaline and often bi-fid. Lodicules absent or very feebly developed. **Gynoecium**—carpel 1; ovary obliquely ovoid and [illegible] 1 into 1), very long and bi-fid at the [illegible] hang out in a tuft from the top of the [illegible] nown as caryopsis (see p. 157) It is [illegible] ee fig 7B). It shows hypogeal germination (see fig. 14). Flowers are anemophilous, i.e. pollination is brought about by wind (see fig. 296), and after fertilization the female spadix develops into the maize cob.



Graminaceae. FIG. 810. Maize or Indian corn (*Zea mays*). *A*, adventitious roots; *B*, female spadix in the axil of a leaf; *C*, female spikelet; *D*, ripe cob; *E*, a panicle of male spikelets; *F*, two pairs of male spikelets; and *G*, a male spikelet dissected out—*G* I, first empty glume; *G* II, second empty glume; *P'*, palea of the lower flower; *FG*, flowering glume; *P*, plaea of the upper flower; *L*, lodicules; and *S*, three stamens of the upper flower.

Family 7—*Cyperaceae* (3,500 sp.)

The general habit of *Cyperaceae* is similar to that of *Graminaceae* but the following points should be noted:

Habit—herbs. Stem solid, usually triangular. Leaves simple, alternate, tristichous; ligule absent; sheath closed. The total inflorescence may be a spike or panicle or globose head, but

the unit of inflorescence is a spikelet. In each spikelet there may be one or more flowers, but each is borne in the axil of a glume and is minute in size, unisexual or bisexual. **Perianth** usually represented by 3 or 6 bristles or scales, or absent. **Androecium**—stamens usually 3; anthers basifixed, linear. **Gynoecium**—carpels (3), syncarpous; ovary 1-celled, with 1 ovule, superior; stigmas 3, long and feathery or papillose. **Fruit** a small nut or nutlet. **Seed** albuminous. Pollination is brought about by wind.

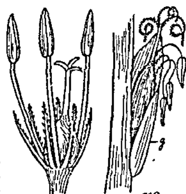


FIG. 811 FIG. 812
Fig. 811. Flower of *Scirpus*.
Fig. 812. Flower of *Cyperus*; *g*, a glume.

Examples: sedge (*Cyperus rotundus*; B. & H. MUTHA), *C. tegetum* (B. MADUR-KATI), *Kyllinga*—common weeds with white globose heads, *Scirpus grossus* var. *kysoor* (B. KESOOR), club rush (*S. littoralis*)—found in the Sundarbans, *S. articulaus* (B. PATPATI), *Carex*, *Juncellus inundatus* (B. PATI), and *Fimbristylis*—common weeds. The family is of little economic importance.

Distinctions between *Graminaceae* and *Cyperaceae*

	Graminaceae	*Cyperaceae*
Stem	... Cylindrical; solid or hollow.	Triangular; solid.
Leaf	... Distichous, with ligule; sheath split open.	Tristichous, without ligule; sheath closed.
Inflores.	... Spike or panicle of spikelets.	Spike or panicle or head of spikelets.
Glumes	.. Glumes 3 and palea 1; lower 2 empty and 3rd one flowering.	A flower in the axil of a glume.
Flower	... Usually bisexual.	Unisexual or bisexual.
Perianth	... Represented by two lodicules.	Represented by 3 or 6 bristles or scales or absent.
Stamens	... Usually 3; sometimes 6; anthers versatile.	Usually 3; rarely 6; anthers basifixed
Carpels	... Only 1, with 2 stigmas.	(3), syncarpous, with 3 stigmas.
Fruit	... Caryopsis.	Nutlet.

PART VIII
EVOLUTION AND GENETICS

CHAPTER I

ORGANIC EVOLUTION

It is now an established fact that higher and more complex forms of plants and animals have evolved from earlier and simpler forms. At one time, however, it was believed that different species of animals and plants were created in the forms in which they exist today. Even today some are under the impression that minute organisms like bacteria develop spontaneously in putrefying material. Louis Pasteur, a French scientist and founder of the science of Bacteriology, proved definitely in 1864 that spontaneous generation is beyond any doubt of possibility. Bacteria are present everywhere, and whenever they get a suitable medium they grow. The old view is, therefore, no longer tenable. Moreover, there is evidence, to show that plants and animals have evolved from pre-existing forms, and not been created. Fossil records are particularly instructive in this respect. Rocks of different ages show impressions of animals and plants of different types,—earlier-formed rocks showing remains of simpler organisms, and later-formed rocks of more advanced and complex types. Ancient rocks show no trace of higher animals and plants. They did not exist in those early geological ages. Thus from fossil records both animals and plants may be traced back to their earliest forms. If we try to go further back the pertinent question arises, 'What is the origin of life?', or, in other words, 'How did the protoplasm, the physical basis of life, first come into being?' It is believed that life came into existence as a speck of protoplasm as a result of certain chemical and physical changes in certain inorganic materials under adventitious circumstances. These changes are not, of course, clearly understood. However, once protoplasm was formed its continuity has been maintained through millions and millions of years up to the present form of life.

Life originated in water (in the sea) and it is generally thought that the first plants were some forms of aquatic bacteria. These organisms could manufacture organic substances from inorganic materials. The energy required for this syn-

thetic process was obtained not from sunlight but from oxidation of iron compounds, sulphur compounds, etc. The next phase in evolution was possibly the appearance of blue-green algae. Primitive unicellular animals might have originated at this stage. Later, with the appearance of green algae which could utilize sunlight as a source of energy the trend of evolution leading to higher plants became established. Animals, always non-green in colour, formed another line of evolution. At the ancient age of the earth which comprised several millions of years numerous forms of algae and primitive marine animals formed the dominant feature of the sea. Life remained confined to water for many millions of years. At a later stage of evolution life invaded the land. Organisms of this stage had to depend on both water and land for the completion of their life-cycle. Such organisms are called amphibians, the living representatives being frogs among animals, and mosses and ferns among plants. Later forms are adapted to land conditions.

Evidences of Organic Evolution

1. ***Geological Evidence.*** Actual petrified remains of ancient plants and animals, or impressions left by them in rocks, are called **fossils.** They bear sound evidence regarding the existence of plants and animals in different geological ages, and help us to trace the gradual increase in the complexity of life The surface of the earth consists of layers or strata of rocks formed in different ways in different ages. The strata of rocks, thus formed successively, have been found to bear fossils of particular types of plants and animals. Thus ancient rocks show earliest and simplest types of plants and animals, e g. marine algae and marine invertebrate animals; later-formed rocks show more advanced and complex types, e.g. sea-weeds, mosses, ferns, gymnosperms and higher invertebrates and lower vertebrates, with ferns and fishes dominating and amphibians making their appearance. Later strata show ferns waning, gymnosperms dominating and land vertebrates increasing. Next period records the probable origin of dicotyledons and the appearance of mammals, while ferns and gymnosperms begin to wane. Subsequent to this period we find dicotyledons and mammals increasing, and monocotyledons (particularly palms and grasses), birds and reptiles appearing. Next comes the period of forests, higher mammals and birds. This period is followed by decrease of forests, extinction of many large mammals and trees, and appearance of man. Recent period records dominance of man (civilized)

and of herbaceous plants. Fossil record, therefore, is of considerable importance in elucidating the problem of evolution Fossils, however, show wide gaps in the evolutionary history of plants and animals. A very interesting case of missing link may be mentioned here. A group of extinct plants which developed abundantly in the carboniferous (coal) age has been discovered in fossil conditions. They were fern-like in general appearance and in many other respects, but they produced ovules (seeds were, however, not found in them) and also formed cambium like those of living gynosperms. They evidently represented a transitional stage between pteridophytes and cycad-like gymnosperms, and are called *seed ferns* or *pteridosperms*.

2. **Taxonomic Evidence.** According to resemblances and differences we classify plants and animals into certain well-marked groups, members of each group resembling each other more closely. It is difficult to conceive of these similarities in forms without having recourse to evolution. Besides, it is seen that between two or more species of a particular genus there are intermediate forms linking such species (*intergrading species*). If species were constant the occurrence of such forms could not be accounted for.

3. **Morphological and Anatomical Evidence.** The structural similarities of roots, stems, leaves, flowers and other morphological characters among certain groups of plants, and of bones and other organs among certain groups of animals, and the successive stages in the development of such organs from simpler to more complex forms evidently show evolutionary tendencies among plants and animals. Morphological similarities in the type of venation, shape of corolla, cohesion or adhesion of stamens and similar other morphological traits among a group of plants are very significant in the problem of evolution. Similarly, the study of types of wood or xylem, development of stele, nature of tracheids and vessels among the higher cryptogams, gymnosperms and angiosperms, and of the development of tissues and nerves among animals lends additional support to the theory of evolution. Sometimes instead of progressive evolution some parts of plants show a reversion to ancestral type.

4. **Embryological Evidence.** The study of the nature and development of the embryo shows a great resemblance among certain groups of plants and of animals. The development shows the evolutionary change that has taken place through successive stages. Besides, in all cases one fact at least is

common, i.e. the embryo develops from the egg-cell or ovum. Sometimes some organs of plants or animals show a striking resemblance to certain forms from which they have possibly been derived. Thus when a fern spore germinates it resembles a filamentous alga; it then assumes a thalloid form resembling a liverwort; and finally it grows into a fern plant. The frog passes through tadpole stage resembling a fish which is supposed to be its ancestor. Seedlings sometimes show their resemblance to plants which may be their ancestors. Thus in Australian *Acacia* the seedling shows a bipinnate compound leaf like other species of *Acacia*, although adult Australian *Acacia* has only the winged petiole or rachis (phyllode) without the compound leaf.

5. **Evidence from Geographical Distribution.** It has been seen that many allied *species of plants in their wild state remain confined to a particular area.* The explanation is that they sprang up from a common ancestor in that region and could not migrate owing to some barriers such as high mountains, seas and deserts. Thus we find that double coco-nut palm (*Lodoicea*) originated in Seychelles, traveller's tree (*Ravenala*) in Madagascar, *Eucalyptus* in Australia, cacti in the dry regions of tropical America, cactus-like spurges (*Euphorbia*) in the deserts of Africa, etc., often with allied species near together, showing thereby that all the allied species have evolved from the same ancestral species.

6. **Vestigial Structures.** It is commonly observed that there are certain degenerated parts of plants and animals, which do not serve any useful purpose. Such parts are known as vestigial structures. It is assumed that in the early ancestry of the organisms concerned, such parts were functional and in course of evolution these parts have degenerated having ceased functioning. Thus we find that in *Asparagus* with the development of the green stem and the cladodes the leaves have been reduced to scales. In parasites like broomrape (*Orobanche*) and dodder (*Cuscuta*) leaves have been reduced to scales in the absence of their normal function of photosynthesis. There are many instances of reduction of floral organs, particularly stamens, in many families. The presence of vestigial structures is explained on the basis of the early history of the race and the course of evolution.

Mechanism of Organic Evolution

Variation. Variation is the rule in nature. No two forms, belonging even to the same species, are exactly alike. The

differences between them are spoken of as **variations.** Variations are the basis on which evolution works. Variations may take place in different organs of plants and animals in respect of shape, size, colour, number, form and in other directions, and may be continued or discontinued in the subsequent generations. Variations may be continuous or discontinuous. **Continuous variation** means the variation or fluctuation of the individuals around the specific type through minute gradations in one or more characters. Such variation may be seen in the type of leaves, flowers, fruits, seeds, and even in the habit of the plant. In this type of variation a continuity or gradation is maintained between the individuals of the species. This was the basis of Darwin's theory of *natural selection.* Darwin held that the minute variations of the individuals are preserved and accumulated through natural selection, and transmitted to the offspring. **Discontinuous variation** or mutation, on the other hand, means sudden and sharp variation of one or more individuals of the species in respect of one or more characters. The individuals show no gradations, as in the previous case, but at once assume new forms. The sharp variation of this type is directly inherited by the offspring. This is De Vries' view. As mutation occurs suddenly and spontaneously there is no knowing when a new form will appear by this process. There are many cases of mutation on record.

[illegible] understood Variation may be due [illegible] (or gametes), or it may be due to [illegible]g the body (or somatic) cells. In the first case it may be that an inherent tendency exists in the gametes to vary; consequently individuals that are produced from these gametes tend to vary in one or more directions; or, variation may be due to the blending of two sets of parental characters as a result of fusion of two gametes of opposite sexes. In the second case variation meaning adaptation may be due to the direct influence of the environment upon the body cells. The new characters, thus adapted or acquired during the lifetime of the individuals, are not, however, believed to be inheritable The cause of this kind of variation or adaptation may be like this: the body cells that receive the impressions from outside may throw them to the gametes; the gametes then are in a position to transmit them to the progeny. But this is disputed.

Adaptation. Adjustment of plants and animals to their environment by means of special structures or of functions are spoken of as **adaptations.** In ecology numerous instances of adaptations are met with. Adaptation has also an important bearing on evolution. Plants have an inherent capacity to adapt themselves to their environment. Many of them are plastic in nature, and consequently are in a position to adapt themselves to changed conditions according to their needs. This is more particularly true of animals. It is Lamarck's

view that adapted structures are fixed and inherited by the offspring, so far at least as the same environment continues (inheritance of acquired characters). According to this view individuals of the species that invade two or more situations will give rise to a corresponding number of *new forms*.

Heredity: Inheritance of Characters. Heredity means transmission of characteristics and qualities of parent forms to their offspring. This is evident from the fact that a particular species of plants on reproduction gives rise to the same species and to no other. Although no two forms are exactly alike, still offspring bear the closest resemblance to their ancestral forms, and they also resemble one another most closely with, of course, individual differences. It is a controversial point as to which characters meaning variations are transmitted and which not. It is, however, a fact that evolution is not possible *without* variation. Heredity gives rise to variation in the offspring in some directions, and this variation is the cause of organic evolution. Now the question is, 'What is the mechanism of inheritance?' In the process of reproduction we find that two reproductive nuclei (i.e. gametes—male gamete of the pollen-tube and egg-cell of the embryo-sac) of opposite sexes, each with x chromosomes, fuse to give rise to the oospore, the embryo and ultimately the mature plant, each with $2x$ chromosomes. Thus inheritance of characters takes place through the said nuclei. In 1884 Strasburger and Hertwig established the fact that it is through *the chromosomes that characters are transmitted from generation to generation*. It is, however, obvious that any particular character of the parent (e.g. colour of flower) cannot be found in the chromosomes; but it may be safely assumed that something representing that particular character must be present in them. That 'something', obscure though it is, is called the **factor** or **determiner** or gene for that particular character, and the genes located in the chromosomes of the gametes or reproductive nuclei are responsible for all the characteristics of the parent plants and their transmission to the offspring. The theory of genes in the chromosomes was introduced by Morgan in 1926.

Theories of Organic Evolution

Pre-Darwinian Ideas of Evolution. The idea of evolution dates back to the earliest period of human civilization. The oldest theories discussed much about the origin of life, but these were more or less only *speculations rather* than facts. These theories or speculations may be sum-

marized under three heads: (1) theory of eternity of the present conditions, (2) theory of special creation, and (3) theory of catastrophism. The believers of the first theory argue that there is neither beginning nor end of the universe. The life forms which existed millions of years ago have remained unchanged up till the present day and would continue in the same state throughout eternity. The theory of special creation was preached for many centuries by Christian Church authorities. Father Suarez, a Spanish priest, advocated this theory. According to him the earth was made in six days. On the first day the earth was made out of nothing. On the third day the ancestors of plants and animals suddenly came into existence. Finally on the fifth and sixth days the ancestors of all living beings suddenly appeared. This theory of Father Suarez was believed up to the middle of the nineteenth century in Europe. Cuvier, a palaeontologist, carried on research for a long time in Paris and brought to light the theory of catastrophism. He was working on fossil fauna. He believed that at one time catastrophes, e.g. subsidence of the earth's crust below the sea or its emergence out of the sea, were world-wide and these brought about the death of the older fauna ; such extinction of the older fauna caused the creation of a new fauna. The new creation, he believed, took a long time covering millions of years due to changed conditions of the environment brought about by the catastrophes.

The idea of organic evolution, although believed to be a modern one, can be traced back to many centuries. The evolutionary idea emanated from the researches of many Greek philosophers. Empedocles is regarded in this respect as the father of evolutionary ideas. He believed that organisms did not improve through successive generations but nature tried to produce perfect organisms many times, and during this period unfit forms were eliminated. Then came the great philosopher Aristotle. He believed that there was an inherent tendency among the organisms in nature to attain greater and greater perfection according to the changes in the environment, and that was the reason why there was a perfect gradation from the lowest to the highest evolved in nature. After this period there was a gap in the progress of the evolutionary ideas until the coming of the evolutionists like Linnaeus, Buffon, Erasmus Darwin, Lamarck and Charles Darwin.

Lamarck's Theory : Inheritance of Acquired Characters. The first modern theory to explain the cause of evolution was put

forward by the French biologist Lamarck in 1809. Lamarck held the view that environment plays the principal part in the evolution of living organisms. He noted many instances where individuals of the same species grown under different conditions showed marked differences between them. Plants grown in the shade develop larger leaves. In the dry soil the root system becomes more extensive than in the wet soil. In darkness leaves do not develop chlorophyll and the stem becomes weak and drawn out. Many plants leading an amphibious life show heterophylly. From such observations Lamarck concluded that plants react to external conditions, and that as a result of cumulative effects produced by the changed conditions through successive generations new species make their appearance. In the case of plants, according to Lamarck, changes in characters (or adaptations) are brought about by the direct action of the environment, and in the case of animals these are brought about by the use and disuse of parts. The use or exercise of certain parts results in the development of those parts; while disuse or want of exercise results in the degeneration of the parts. He further believed that new characters, however minute, acquired in each generation under changing conditions of the environment, are preserved and transmitted to the offspring. The classic example cited in this connection is that of the giraffe. Lamarck's view was that horse-like ancestors of these animals living in the arid region in the interior of Africa had to feed on the leaves of trees. They had necessarily to stretch their limbs to reach up to the leaves. This use or exercise resulted in the lengthening of the neck and the front legs. Thus his theory resolves itself into three factors, viz. (*a*) influence of the environment, (*b*) use and disuse of parts, and (*c*) inheritance of acquired characters. His theory is open to certain objections. One objection is that adaptations due to the influence of the environment are very slight and superficial. Another objection is that the inheritance of acquired characters has not been proved yet. In fact we find that if seeds are grown in the original habitat even after many years the plants return to their original form.

Darwin's Theory: Natural Selection. The next theory to solve the problem of evolution was put forward in 1859 by Charles Darwin and published in his '*Origin of Species by Means of Natural Selection*'. His theory based on a mass of accurate observations and prolonged experiments led the whole scientific world believe in the doctrine of evolution. His theory, called the theory of natural selection, is based on three

important factors: (*a*) over-production of offspring and a consequent struggle for existence, (*b*) variations and their inheritance, and (*c*) elimination of unfavourable variations (survival of the fittest).

Struggle for Existence. If all the seeds of any particular plant were to germinate and all seedlings to grow up into full-sized plants, a very wide area would soon be covered by them in course of a few years. If other plants (and also animals) were to increase at this rate, a keen competition, called the struggle for existence, would be set up at once among them because supply of food, water and space would fall far short of the demand. A struggle would soon ensue, resulting in the destruction of huge numbers of individuals. This is evident from the fact that from year to year the numbers of animals and plants are more or less constant.

Variations and their Inheritance. It is known to all that no two individuals, even coming out of the same parent stalk, are exactly alike. There are always some variations, however minute they may be, from one individual to the other. Some variations are suited to the conditions of the environment, while others are not. According to Darwin these minute variations are preserved and transmitted to the offspring, although no cause for these variations was assigned by him.

Survival of the Fittest. In the struggle for existence individuals showing variations in the right directions survive, and these variations are transmitted to the offspring; others with unfavourable variations perish. This is what is called by him 'survival of the fittest'. The survivors gradually and steadily change from one generation to the other, and ultimately give rise to new forms. These new forms are better adapted to the surrounding conditions.

Darwin's observations on the variations of domestic animals and cultivated plants served him as a clue to the elucidation of his theory of natural selection. Sometimes such extensive changes are found in course of several generations that it becomes difficult to believe that the first form has given rise to the last. Further, for the purpose of having a desired type, breeders and florists take note of certain variations among individuals, select them for future generations, rejecting and destroying the rest. They grow the selected types, generation after generation, until the desired result is obtained. New types are seen to appear by this process, called *artificial selection*. Many cultivated flowers and vegetables often show a

number of varieties, and in course of time these variations become well marked.

Natural Selection. Now Darwin's explanation of natural selection is this: animals and plants are multiplying at an enormous rate. As we know, no two individuals are exactly alike, the new forms naturally show manifold variations. Some variations are favourable or advantageous so far as their adaptation to the conditions of the environment is concerned, and others are not so. Owing to an excessive number crowding together a keen struggle for existence ensues. And in this struggle those that have favourable variations and are, therefore, better fitted naturally survive, and the rest perish. Through this survival of the fittest the species change steadily owing to preservation and transmission of minute variations, and gradually give rise to newer forms. Darwin called this process 'natural selection' from analogy to artificial selection. It is the environment that selects and preserves the better types and destroys the unsuitable forms.

Although Darwin receives the fullest credit for bringing about the final acceptance of the doctrine of evolution, his theory is open to certain doubts. It is true that natural selection is operative in the preservation of certain forms and destruction of others. But still some doubts have been expressed regarding the process being the cause of production of new species. Some of the reasons for these doubts are as follows: (*a*) are slight variations of any decided advantage in the struggle for existence? It is only the perfected organs that are helpful to organisms, and not the organs during the process of perfection; (*b*) it is doubtful if slight variations can help the individuals to go beyond the boundary of the species. This has never been found possible by artificial selection in breeding experiments; and (*c*) there are many organs which are not of any apparent use to the organisms. If nature selects suitable forms and features, why were the rest swept out of existence?

De Vries' Theory: Mutation. Another theory to explain the cause of evolution was advanced by the Dutch botanist Hugo De Vries in 1901. He held that small variations, which Darwin regarded as most important from the standpoint of evolution, are only fluctuations around the specific type. These variations are not inheritable. De Vries held that large variations appearing suddenly and spontaneously in the offspring in one generation are the cause of evolution. These variations De Vries called 'mutations'. He observed an evening primrose (*Oenothera lamarckiana*), introduced from America, growing in a field in Holland. Among numerous plants he found two types quite distinct from the rest. These new types were not described before, and having bred true he regarded them as distinct species. *Oenothera lamarckiana* and the new species were removed to his garden at Amsterdam, and cultivated through many generations. It was found that among

thousands of seedlings raised a few appeared that were different from the rest. These when raised, generation after generation, always came true to types. These new forms are known as *mutants*. He concluded that his mutation theory explains the cause of evolution. While De Vries agreed with Darwin's view, regarding natural selection weeding out unsuitable forms, he held the view that new species are not formed, as Darwin said, by the slow process of continuous variations.

Weismann's Theory: Continuity of Germplasm. An ingenious theory explaining the cause of variation and evolution was put forward by Weismann in 1895. He divided the protoplasm of the animal or plant body into *somatoplasm* which gives rise only to somatic or body cells and *germplasm* which produces the reproductive cells. According to him it is only the germplasm which is continuous from one generation to another and is actually the bearer of hereditary characters. During reproduction the fertilized egg gets the paternal germplasm from the sperm and the egg-cell respectively. In the nuclei of both somatic and germ cells there are certain factors which determine the character of the cell. It is believed that each somatic cell has a single factor, whereas a germ cell contains all the factors that are found in the somatic cells of the adult plant or animal. The inheritance of characters by the offspring depends upon these factors of the germ cells only. There is always a struggle for existence among these factors, and this results in a *germinal selection*. The stronger factors survive and are readily transmitted from one generation to another. Hence any mutation in the germplasm or any variation resulting from the struggle among the factors in the germ cells can only be handed down from generation to generation. Weismann's theory supports Darwin's theory of natural selection, but it has been criticized by many scientists as purely speculative.

CHAPTER II

GENETICS

Genetics is the modern experimental study of the laws of inheritance (variation and heredity). Cytology, dealing with the structure, number, behaviour, etc., of chromosomes, is of immense value in understanding many intricate facts connected with genetics since chromosomes are the bearers of heritable characters. It is also to be remembered that in addition to their characteristic form and individuality their number is always constant for each species. First scientific studies on

genetics were carried on by Gregor Mendel. He entered a monastery in Brunn, Austria, where he carried on his scientific investigations on hybridization of plants. The results of his eight years' breeding experiments were read before the Natural History Society of Brunn in 1865, and in the following year these were published in the transactions of that Society. But his work remained unnoticed until 1900, when three distinguished botanists, Hugo De Vries in Holland, Tschermak in Austria and Correns in Germany, discovered its significance. Since then Mendel's work has formed the basis of the study of genetics. Mendel died in 1884 before he could see his work accepted and appreciated.

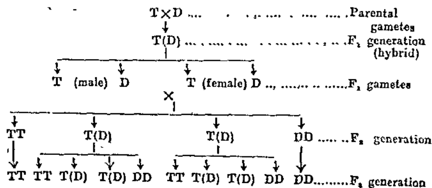
Plant Breeding. The subject of plant breeding, although developed in recent times on modern scientific lines after Mendel's discoveries, was known in early times to the Egyptians and Assyrians. During the eighteenth century several crosses were made by many workers and interesting results obtained. New varieties were produced by them by such crosses, but the actual mechanism of fertilization remained unravelled. About 1830 the development of the pollen tube and its approach to the ovule were observed. In 1846 Robert Brown, an English botanist, did a considerable work on this problem. But it was in 1884 that Strasburger cleared up the whole process of fertilization and the transmission of hereditary characters through the reproductive nuclei, i.e. male gamete and egg-cell, which are directly concerned in fertilization. In the nineteenth century Gartner made extensive crosses—thousands of them—involving nearly 700 species and obtained about 250 hybrids. His work was published in 1849.

Plant breeding consists in producing offspring by artificially pollenizing the stigma of another flower according to certain principles. Two varieties or species or even genera differing from each other in one or more characters may thus be crossed and the results studied. The offspring or hybrids, as these are called, will usually show in the first generation some of the characters of each parent or will be intermediate between the two parent forms. In the subsequent generation the dormant characters are seen to appear in the offspring. The offspring resulting from the crossing of red-flowered and white-flowered plants, of tall and dwarf plants, and of other plants with contrasting characters are said to be **hybrids**. It is often seen that the hybrids are more vigorous than their parents. This phenomenon is known as ***hybrid vigour*** or ***heterosis***—the term suggested by Shull in 1914. Since the characters of parent

forms can be combined in the offspring by artificial breeding or **hybridization,** as it is called, it is possible to obtain new varieties with desired characters by selecting parent plants with suitable characters. Thus new varieties of economic and ornamental plants can be produced by hybridization. Herein lies the importance of plant breeding (see pp. 596-8).

Mendel's Laws : Laws of Inheritance

Monohybrid Ratio. Mendel selected for his work the common garden pea. In pea he found a number of contrasting characters—flowers purple, red or white; plants tall or dwarf; and seeds yellow or green, smooth or wrinkled. At a time he concentrated his attention on only one pair of characters, and traced them carefully through many successive generations. In one series of experiments he selected tallness and dwarfness of plants. The results he achieved in these experiments were the same in all cases. It did not matter whether he took the dwarf plant as the male one and the tall plant as the female one, or vice versa. He selected a pea plant, 6 feet in height, and another, 1½ feet in height. He brought about artificial crossings between the two. The progeny that resulted from these crossings were all tall. This generation, known as the first hybrid generation or F_1 generation, was inbred. Seeds were collected and sown next year. They gave rise to a mixed generation of talls and dwarfs (but no intermediate) in the ratio of 3 : 1, i.e. three-fourths talls and one-fourth dwarf. This generation is known as the second hybrid generation or F_2 generation. All dwarfs in subsequent generations bred true producing dwarfs only. Seeds were collected separately from each tall plant and sown separately. It was seen that some of them bred true to type; while others again split up in the same ratio of 3 : 1.



Mendel's monohybrid ratio.

Theoretical explanation of the above behaviour was given by Mendel in the following way:

1. **Independent Unit Characters.** This means that all characters of the plant are units by themselves, being independent of one another so far as their inheritance is concerned. There are certain factors or determiners (now called *genes*) of unit characters, which control the expression of these characters during the development of the plants.

2. **Dominance.** The characters, as stated above, are controlled by factors or genes. These occur in pairs in a linear fashion in the chromosome and are responsible for tallness and dwarfness separately. One factor may mask the expression of any one character. Thus in F_1 generation all the individuals are tall, the other character remaining suppressed. The character that expresses itself in the F_1 generation is said to be *dominant*, and the character that does not appear in the F_1 generation is said to be *recessive*. The recessive character is, however, always present in the F_1 individuals. In the above experiment tallness is the dominant character and the suppressed dwarfness is the recessive character. The contrasting pairs of characters are called **allelomorphs**. Thus tallness and dwarfness are allelomorphs.

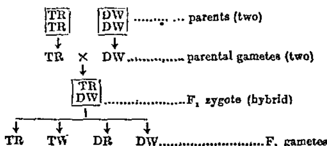
3. **Purity of Gametes.** It is evident that the F_1 zygote contains factors for both the alternative characters, namely, tallness and dwarfness, although tallness has expressed itself in the F_1 generation. These factors remain associated in the somatic cells of the F_1 individuals throughout their whole life. Later in the life-history when spores—pollen grains and megaspores (and subsequently gametes)—are formed as a result of reduction division, the factors located in homologous chromosomes become separated out, and each of the four spores (and gametes) will have only one factor (tallness or dwarfness) of the pair but not both, i.e. a gamete becomes pure for a particular character. This becomes evident from the nature of F_2 progeny. When the F_1 zygote produces the progeny of the F_2 generation, segregation of characters takes place in the following proportion—1 : 2 : 1, one-fourth pure talls, one-fourth pure dwarfs, and half impure talls.

Phenotype and Genotype. When two individuals are similar in their external appearance but differ in their genetic make-up, they are referred to as phenotypes, and when their genetic composition is the same, they are referred to as genotypes. Thus in the above Mendel's experiment *TT* and *T(D)* individuals of the F_2 generation are alike externally although

they differ from each other with respect to their genes; these individuals, therefore, belong to the same phenotype. But because of their differences in genetic composition they are said to belong to different genotypes, TT to one and T(D) to another. It may further be noted that when the individuals have similar gene pairs they are said to be *homozygous*, and when dissimilar they are *heterozygous*. Thus TT and DD individuals are homozygous and T(D) individuals are heterozygous.

Mendel also experimented on other pairs of alternative characters, and he found that in every case the characters followed the same scheme of inheritance. Thus in garden pea he discovered that coloured flower was dominant over white flower; yellow seed over green seed; and smooth seed over wrinkled seed.

Dihybrid Ratio. We have considered above the monohybrid ratio, i.e. the ratio obtained when only a single pair of contrasting characters is taken into account. We will now take up the dihybrid ratio, i.e. consider the results of two pairs of contrasting characters. Mendel selected a tall plant with red flowers and a dwarf one with white flowers. Four unit characters are, therefore, concerned in the dihybrid ratio. Factors for tallness or dwarfness and red flowers or white are independently inherited, and may be considered to be located in separate chromosome pairs. Artificial crossing was brought about between these two plants. In the F_1 generation all individuals were tall with red flowers; for tallness is dominant over dwarfness, and coloured flowers dominant over white. When the seeds from the F_1 generation were grown, a segregation of characters showing all possible combinations, took place in



Male gametes of F_1

Female gametes of F_1	TR	TW	DR	DW
TR	TR TR (1)	TR TW (2)	TR DR (3)	TR DW (4)
TW	TW TR (5)	TW TW (6)	TW DR (7)	TW DW (8)
DR	DR TR (9)	DR TW (10)	DR DR (11)	DR DW (12)
DW	DW TR (13)	DW TW (14)	DW DR (15)	DW DW (16)

Hybrids of F_2 generation

Mendel's dihybrid ratio

the following proportions: 9 red talls, 3 white talls, 3 red dwarfs, and 1 white dwarf. This 9: 3: 3: 1 is the dihybrid ratio.

Nos. 1, 2, 3, 4, 5, 7, 9, 10, 13 are tall-red = 9
Nos. 6, 8, 14......................................tall-white = 3
Nos. 11, 12, 15..........................dwarf-red = 3
No. 16...dwarf-white = 1

It will further be noticed that Nos. 1, 6, 11 and 16 are homozygous (i.e. they have two similar gametes), breeding *true; while the rest are heterozygous* (i.e. they have two dissimilar gametes), segregating in the next generation.

No. 1 (TRTR) will breed true for tall-red
No. 6 (TWTW) .... .tall-white
No. 11 (DRDR)........ .... dwarf-red
No. 16 (DWDW)........................ dwarf-white

Polyhybrid Ratio. In this way Mendel extended the number of characters; *for example, when three pairs* of contrasting characters were taken—tall and dwarf, red flower and white, and smooth seed and wrinkled, it was found that in the F_1 generation all individuals were *tall with red flowers* and smooth seeds. In the F_2 generation they split up in the following proportion: 27 TRS, 9 TRW', 9 TWS, 9 DRS, 3 TWW', 3 DRW', 3 DWS, and 1 DWW'.

Chromosome Mechanism in Heredity and Evolution

Recent work of Morgan and his colleagues on a fruit-fly (*Drosophila melanogaster*) has led them to put forward the chromosome theory of heredity. According to this theory chromosomes are the bearers of hereditary characters, and the *genes* which are responsible for the production of characters are arranged in a linear fashion in the chromosomes. The continuity of chromosomes throughout the life-cycle of a plant is evident. Plants reproduce by the fusion of male and female gametes, and the zygote so formed develops into the seedling and the mature plant. So the parental characters must be transmitted to the offspring through these gametes. The somatic (body) cells of the sporophyte have $2x$ chromosomes, of which x chromosomes are of paternal origin and x of maternal origin. When the gametes are produced the sporophytic number ($2x$) is reduced to half (x) by meiosis so that each gamete has x chromosomes. As soon as the gametes fuse to form the zygote, $2x$ are regained. The inheritance of the parental characters by the offspring is carried on by the genes which are ultra-microscopic particles occurring in pairs (one paternal and one maternal) in linear series in the chromosomes. When the chromosome splits, the genes become equally apportioned to the two chromatids. A particular plant or animal has a large number of gene pairs but comparatively few chromosomes and, therefore, each chromosome must carry several genes in its body. A gene (or a pair) is a factor or determiner responsible for the production of a particular character, e.g. colour of flower, shape of leaf, size of fruit or any other character. The several characters of a plant or an animal are, however, always influenced by the interaction of a number of genes. Although some investigators speak of transmission of hereditary characters through the cytoplasm of the egg or the sperm, yet it is regarded as of secondary importance at present. Whether the transmission of characters is chromosomal or cytoplasmic, the characters of mature plants and animals are modified to a great extent by environmental influences.

Chromosomes play an important role in evolution. New species of plants may arise due to changes in or loss or degeneration of genes or even the appearance of new genes or due to changes in the proportion of genes, known in all cases as 'gene' mutations. The cause of these changes is, however, yet unknown. The simple case of 'gene' mutation was observed by De Vries in evening primrose (*Oenothera lamarckiana*) which

led him to put forward the 'mutation theory' of evolution. It has been seen that now and then dwarf plants of evening primrose have suddenly appeared in the field from normal plants, and these subsequently bred true. These are new species which, according to De Vries, have evolved only by 'gene' mutation. Sometimes a red- or blue-flowered species has been seen to give rise suddenly to white-flowered species. The old gene, it is assumed, has changed and a new character has developed. New species of plants are also produced by a sudden increase in the number of chromosomes. Thus there may be $2x$, $4x$, $5x$, $6x$, $7x$, $8x$, $9x$ or $10x$ or more or even a variable number. When this increased number is a multiple of haploid, it is expressed as **polyploid** (*or heteroploid*). There are several cases showing polyploidy, e.g. wheat, maize, evening primrose, rose, cotton, tomato, *Datura*, etc. Polyploid plants often show large variations and are distinct from normal plants with diploid chromosomes. *Polyploidy may lead to the development of perennial types from annual types.* Polyploidy has been found to occur in several wild and cultivated plants under natural as well as artificial conditions such as lowering or raising of temperature, application of dilute poisons like colchicine, repeated cutting back, X-ray treatment, etc. When the chromosome number is not an exact multiple of haploid, it is expressed as **aneuploid.** Aneuploidy may be due to *incomplete separation of chromosomes. Thus evening primrose* has produced new forms with 15 $(2x+1)$ chromosomes, and *Datura* with 25 $(2x+1)$ chromosomes. It is thus seen that chromosomes play an important part in the evolution of new forms.

Economic Importance of Plant-breeding. The subject of plant-breeding has been scientifically developed to such an extent in recent years that it is now recognized as the best practical method for the improvement of various crops—food grains, vegetables, pulses, oil-seeds, fruits, industrial plants, fodder crops and many other plants of economic importance and of aesthetic value as regards their productiveness, quality, colour, size, total yield and other useful characters. It has been found possible by the application of this method to combine the desired characters of parent forms and evolve new types far better than the original types in many respects. Babcock, a leading geneticist, even goes *so far as to say that plants can almost be made to order.* This being so, the subject is considered to be of utmost importance in agriculture and to a great extent in horticulture. By following practical methods of

plant-breeding considerable improvements have already been achieved within the last few decades ; for example, hardy rust-resistant and high-yielding types of wheat plants have been evolved, and the milling and bread-making qualities of wheat grains considerably improved. Several new varieties of rice with higher yield and better quality have been brought into existence. In tobacco the number of leaves per plant and their size and quality have been enhanced. Pea, bean, many vegetables, pulses, oil-seeds, etc., have been considerably improved. Fruits like apple, grapes, peach, pear, plum, orange, strawberry, etc., have similarly been much improved. In fibre-yielding plants like jute, cotton, flax, etc., better quality of the fibre (length, strength and fineness) and also higher yield have already been achieved. New types of maize, potato and tomato—high-yielding and rust-resistant—evolved recently in America are also some of the numerous achievements in this direction. In Russia new varieties of summer and winter wheats and 'perennial' wheat (results of crosses between varieties of wheat and couch-grass), wheat-*Elymus* (result of cross between wheat and *Elymus*—a kind of grass), and barley-*Elymus* (result of cross between barley and *Elymus*) are some of the outstanding features of work in this line. In India also a considerable amount of work has been done in this line on rice, wheat, millets, maize, sugarcane, pulses, oil-seeds, cotton, tobacco, jute, flax, hemp, etc., and improved strains combining high yield, good quality and resistance to pests and diseases evolved by breeding. Pusa wheats deserve special mention in this connexion. New Pusa varieties tolerant to rust and resistant to smut evolved at the Indian Agricultural Research Institute[1] are outstanding successes. A wheat, NP 4, evolved at Pusa was awarded the first prize in several international exhibitions in America, Australia and Africa. In addition this Institute has developed rust-resistant linseeds, wilt-resistant pigeon peas and late blight-resistant potatoes. Besides, highly improved types of chilli, gram, linseed, mustard, etc., evolved through hybridization are some of the special achievements of this Institute. A recent success is the produc-

[1] The Indian Agricultural Research Institute (commonly known as Pusa Institute) was established in 1905 at Pusa in Darbhanga on the liberal donation of £30,000 by an American philanthropist, Mr. Henry Phipps. The laboratory buildings having been irreparably damaged by the great Bihar earthquake in 1934 the Institute was transferred to New Delhi in 1936. At present it has six sub-stations at Pusa (Bihar), Karnal (East Punjab), Simla (Himachal Pradesh), Poona (Bombay), Indore (Madhya Pradesh) and Willington (Madras).

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GLOSSARY OF NAMES OF PLANTS

Botanical name in *italics*; English name in Roman; Indian name in CAPITALS —A. for Assamese, B. for Bengali, G. for Gujarati, H. for Hindi, M. for Malayalam, M'. for Marathi, O. for Oriya, P. for Punjabi, T. for Tamil, and T'. for Telugu.

Abroma augusta (devil's cotton) = A. BON-KOPAHI; B. & H. ULAT-KAMBAL; G. GUMCHI; M'. OLAK-TAMBOL; P. ULT-KAMBAL; T. SIVAP-PUTTUTTI

Abrus precatorius (crab's eye or Indian liquorice)=A. LATUM-MONI; B. KUNCH; H. & P. RATTI; M. KUNNI; M'. GUNJ; O. KAINCHA, GUNJA; T. KUNDOOMONY; T'. GURUGINJA

Abutilon indicum=A. JAPA-PETARI; B. PETARI; G. DABALI; H. KANGHI; M. & T. PERINTHOTTY; M'. MUDRA; O. PEDIPEDIKA; P. PILI-BUTI; T'. THUTIRIBENDA

Acacia arabica (gum tree)=A. TORUA-KADAM; B. BABLA; G. KALOA-BAVAL; H. BABUL; M. & T. KARU-VELAM; M'. BABHUL; O. BABURI; P. KIKAR; T'. NALLATUMMA

Acacia catechu (catechu)=A., B. & M'. KHAIR; G. KHER; H. & P. KATHA, KHAIR; M. KADARAM; O. KHAIRA; T. KADIRAM; T'. KHADI-RAMU

Acalypha indica=B. MUKTO-JHURI; G. VANCHI KANTO; H. KUPPI; M. & T. KUPPAMANI; M'. KHOKALI; O. INDRAMARISHA; P. KOKALI KUPPAMANI

Achras sapota (sapodilla plum)=A. BAPHEDA; B. SHABEDA; H. & M. SAPOTA; M'. CHIKKU; O. SAPETA; P. CHIKU; T. SIMAIYILUPPAI; T'. SIMAIPPA

Achyranthes aspera (chaff-flower)= A. UBTISATH; B. APANG; G. SAFED AGHEDO; H. LATJIRA; M. KATALADY; M'. AGHADA; O. APA-MARANGA; P. PUTH KANDA, KUTRI; T. NAHIROORVY; T'. ATTARENI

Acorus calamus (sweet flag)=A., B. & H. BOCH; G. GODAVAJ; M. VAYAMBU; M'. WEKHAND; O. BACHA; P. WARCH, BOJ, BARI; T. VASAMBOO; T'. VASA

Adhatoda vasica=A. BANHAKA; B. BASAK; G. ADULSO; H. ADALSA; M. ADALODAKAM; M'. ADULSA; O. BASANGA; P. BANSA SURJ, BASUTI; T. ADATODAY; T'. ATARUSHAMMU

Aegle marmelos (wood-apple) = A. & B. BAEL; G. BILIVA-PHAL; H. SIRIPHAL; M. KOOVALAM; M'. BEL; O. BELA; P. BIL; T. VILVAMARAM; T'. BILAMBU

Aeschynomene indica (pith plant)= A. KUNHILA; B., H. & P. SHOLA; M. KADESU, ATTUKEDESU; O. SOLA; T. ATTUNETTEE; T'. JILUGA

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Albizzia lebbek (siris tree)=A., B., H., M'. & P. SIRISH; G. PITO-SARSHIO; M. VAGA; O. SIRISA; T. VAGAI; T'. DIRISANA

Allium cepa (onion) = A. PONORU; B., H. & P. PIYAZ; G. DUNGARI; M. ULLI; M'. KANDA; O. PIAJA; T. VENGAYAM; T'. YERRAGADDA

Allium sativum (garlic)=A. NAHARU; B. RASUN; G. LASAN; H. & P. LASHUN; M. VELUTHULLI; M'. LASUN; O. RASUNA; T. VELLAI-POONDU; T'. TELLAGADDA

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Alstonia scholaris (devil tree)=A. CHATIAN; B. CHHATIM; H. CHA-TIUM; M. EZHILAMPALA; M'. SAT-VIN; O. CHHATIANA, CHHANCHANIA;

tion of a sweet-flavoured tomato with a high vitamin content (result of a cross between a cultivated tomato and a wild South American species). New types of sugarcane evolved at Coimbatore in South India have already become world-famous. These sugarcanes constitute about 90% of the existing varieties now grown in India, and are mainly responsible for the improvement of the sugar industry in India. Although much has already been achieved there is still ample scope for improvement of several crops for food and industry.

It is evident from the foregoing that the subject of plant-breeding has grown so much in economic importance that the agricultural and plant-breeding stations all over the world have now taken recourse to artificial plant-breeding for enhancing the quality and yield of particular crops, and the power of resistance to pests and diseases

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P. SATONA; T. ELILAIPILLAI; T'. EDAKULAPALA

Alternanthera sessilis = B. SENCHI; G. JALAJAMBO; M. KOZHUPPA; M'. KANCHARI; O. MADARANGA; P. CHURA; T. PONNAN KANNI KEERAI; T'. PONAGANTIKURA

Amaranthus spinosus (amaranth) = A. KATA-KHUTURA; B. KANTA-NATE; G. TANJALJO; H. & P. CHULAI; M. MULLANCHEERA; M'. KATE MATH; O. KANTANEUTIA, KANTAMARISHA; T. MULLUKKERAI; T'. MUNDLA KHOTAKURA

Amorphophallus campanulatus = A. & B. OL; G. & M'. SURAN; H. KANDA; M. CHAENA; O. OLUA; P. ZAMIN KANDA; T. KARUNA-KILANGU; T'. THIYA KANDHA

Anacardium occidentale (cashew-nut) = A. KAJU-BADAM; B. HIJLI-BADAM; G., H., M'. & P. KAJU; M. KASHUMAVU; O. LANKA BADAM; T. MUNDIRI; T'. JIDIMAMIDI

Andrographis paniculata = A. KALPA-TITA; B. & H. KALMEGH, MAHA-TITA; G. KIRYATO; M. KIRIYATH-THU; M'. PALEKIRAIET; O. BHUI-NIMBA; P. CHARAITA; T. NELA-VEMBU

Anisomeles indica = B. GOBRA; M. POOTHA-CHETAYAN; M'. GOPALI; O. BHUTA-AIRI; T. PEYAMERATTI

Annona reticulata (bullock's heart) = A. ATLAS; B. NONA; G., H., M'. & P. RAMPHAL; M. ATHA; O. NEUA, BADHIALA; T. & T'. RAMSITA

Annona squamosa (custard-apple) = A. ATLAS; B. ATA; G. & M'. SITA-PHAL; H. & P. SHARIFA, SITAPHAL; M. SEEMA-ATHA; T. & T'. SEETHA

Anthocephalus cadamba = A., B., H. & P. KADAM; G. & O. KADAMBA; M. KADAMBU; M'. KADAMB

Arachis hypogaea (peanut or ground nut) = A., B. & O. CHINA-BADAM; G. MAFFALI; H. & P. mungphali; M. & T. NILAKKADALAI; M'. BHUI-MUG; T'. VERU SANAGA

Areca catechu (areca- or betel-nut) = A. TAMBUL; B., G., M'. & P. SUPARI; H. KASAILI; M. ADAKKA; O. GUA; T. PAKKU; T'. POKA

Argemone mexicana (prickly poppy) = A. KUHUM-KATA; B. SHEALKANTA; G. DARUDI; H. PILA DHUTURA; M. SWARNAKSHEERI; M'. PIWALA DHOTRA; O. AGARA; P. KANDIARI; T. BRAHMADANDU; T'. DATTURI

Aristolochia gigas (pelican flower) = A., B. & O. HANSHA LATA; M. GARUDAKKODI; M'. POPAT VEL; P. BATKH PHUL; T. ADATHINA PALAI

Aristolochia indica (Indian birth-wort) = A. ISWERMUL; B. ISHER-MUL; G. & M'. SAPSAN; H. ISHARMUL; M. ISVARAMMULI; O. GOPOKORONI; P. ANANTMUL, ISHAR-MUL; T. ADAGAM

Artabotrys odoratissimus = A. KO-THALI-CHAMPA; B., G. & H. KANTALI-CHAMPA; M. & T. MANO-RANJINI; M'. HIRWA CHAPHA; O. CHINI-CHAMPA; P. CHAMPA; T'. MANORANJITHAM

Artocarpus integrifolia (jack tree) = A. KOTHAL; B. KANTHAL; G. MAN-PHANASA; H. KATAHAR; M. & T. PILA; M'. PHANAS; O. PANASA; P. KATAR

Artocarpus lakoocha (monkey jack) = A. CHAMA, DEWA; B. DEO, DEO-PHAL; H. DEOPHAL, BARHAL; M'. LAKUCH; O. JEUTA; P. DEHEO

Asparagus racemosus = A. SHATMUL; B. SATAMULI; H. & P. SATAWAR; O. CHHATUARI; M., M'. & T. SATHAVARI; T'. SADAVARI

Averrhoa carambola = A. KORDOI-TENGA; B. KAMRANGA; G. KAMA-RAKHA; H. & P. KAMRAKH; M. IRIMPANPULI; M'. CAMARANGA; O. KARMANGA; T. KAMARANKAI; T'. TAMARTA

Azadirachta indica (margosa) = A. MOHA-NIM; B., H. & P. NIM, NIMBA; G. LIMBA; M. VEPPU; M'. KADU LIMB; O. NIMBA; T. VEMBU; T'. VEPPAI

Baccaurea sapida = A. LETEKU; B. LATKAN; H. LUTKO; P. KALA BOGATI

Balanites sp. = A. HINGOOL; B. HINGAN; G. HINGER; H. & P. HINGOL, HINGU; M. NANJUNTA; M'. HINGANBET; O. HINGU; T. NANJUNDAN

Bambusa tulda (bamboo) = A. BANH; B., H. & P. BANS; G. KATUKA; M. MULAH; M'. BAMBOO; O. BAUNSA; T. MULAI

Barleria prionitis = A. NIL K[illegible] KANTA JHANTI; G. KANT[illegible] H. VAJRADANTI; M. [illegible] BARAM; M'. KORANTI [illegible] KANTA; P. PILA BANSA [illegible] T. CHEMMULLI

Barringtonia acutangula = B. & H. HIJAL; [illegible] PHAL; M. & T. SAM[illegible] M'. PHATRIPHAL; O. SAMUNDRAPHAL

KHARA; P. BHAKHRA; T. T'. PALLERU
thes anguina (snake A. DHUNDULI; B. CHI- G. PADAVALI; H. CHA- M. PADAVALAM, M'. O. CHHACHINDRA; P. T. PUDALAI, T'. POTLA
thes dioica = A. & B. H. & P. PARWAL; M. I; G. & M'. PARWAR; O. T. KOMBUPPUDALAI; T'. POTLA
a foenum-graecum = A. JUTI; B., G., H., O., M'. METHI; M. VENTHIAM; T. YAM
sativum (wheat) = A. U; B. GOM; G. GAHUN; H. GEHUN; M. KOTHAMPU; M'. O. GAHAMA; T. GHODUMAI; THI, GODUMULU
elephantina (bulrush or ele- grass) = B HOGLA; G. GHA- N; H. PATER; M'. PAN ; O. HAUDAGHASA, HOGOLA; TIRA; T. CHAMBU
um trilobatum = A. SAMA- ; B. GHET-KACHU; M. ; T. KARUNKARUNAI, ANAIK- , T'. JAMMUGADDI

lobata = A. BON-AGARA; B. KRA; H. & P. BACHATA; M. M; M'. VAN-BHENDI; O. TA; T. OTTATTI
ria sp. = B. JHANJI; M. ANPAYAL, KALAKKANNAN; M'. CHI VANASPATI; O. BHATUDIA

roxburghii (orchid) = A. U-PHUL; B., H & P. RASNA; RASNA-NAI; M. MARAVAZHA; ANDE; O. RASHNA, MADANGA
ria spinosa = A. KOTKORA, N-TENGA; B. MOYENA; H. ; M'. ALU; O. GURBELI; T. KKARAI; T'. SEGAGADDA
a cineria = B. KUKSHIM; G. I; H. & M'. SAHADEVI; M. AN-KURUNTHILA; O. POKA- A, JHURJHURI; P. SAHDEVI, HIM; T. PUVAMKURUNDAL; ARITIKAMMA
sinensis = A. NESERA-MAH; B. TI; H. BORA; M'. CHAVLI; O. ADA; P. RAUNG; T. THATTA- U; T'. ALACHANDALU
rosea (periwinkle) = A. & B. TABA; H. SADA-BAHAR; M. HUMPA; M'. SADAPHULI; O. IHARI; P. RATTAN JOT

P. SATONA; T. ELILAIPILLAI; T'. EDAKULAPALA

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Anisomeles indica=B. GOBRA; M. POOTHA-CHETAYAN; M'. GOPALI; O. BHUTA-AIRI; T. PEYAMERATTI

Annona reticulata (bullock's heart) =A. ATLAS; B. NONA; G., H., M'. & P. RAMPHAL; M. ATHA; O. NEUA, BADHIALA; T. & T'. RAMSITA

Annona squamosa (custard-apple)= A. ATLAS; B. ATA; G. & M'. SITA-PHAL; H. & P. SHARIFA, SITAPHAL; M. SEEMA-ATHA; T. & T'. SEETHA

Anthocephalus cadamba=A., B., H. & P. KADAM; G. & O. KADAMBA; M. KADAMBU; M'. KADAMB

Arachis hypogaea (peanut or ground nut)=A., B. & O. CHINA-BADAM; G. MAFFALI; H. & P. mungphali; M. & T. NILAKKADALAI; M'. BHUI-MUG; T'. VERU SANAGA

Areca catechu (areca- or betel-nut) =A. TAMBUL; B., G., M'. & P. SUPARI; H. KASAILI; M. ADAKKA; O. GUA; T. PAKKU; T'. POKA

Argemone mexicana (prickly poppy) =A. KUHUM-KATA; B. SHEALKANTA; G. DARUDI; H. PILA-DHUTURA; M. SWARNAKSHEERI; M'. PIWALA DHOTRA; O. AGARA; P. KANDIARI; T. BRAHMADANDU; T'. DATTURI

Aristolochia gigas (pelican flower) =A., B. & O. HANSHA LATA; M. GARUDAKKODI; M'. POPAT VEL; P. BATKH PHUL; T. ADATHINA PALAI

Aristolochia indica (Indian birth-wort)=A. ISWERMUL; B. ISHER-MUL; G. & M'. SAPSAN; H. ISHARMUL; M. ISVARAMMULI; O. GOPOKORONI; P. ANANTMUL, ISHAR-MUL; T. ADAGAM

Artabotrys odoratissimus=A. KO-THALI-CHAMPA; B., G. & H. KANTALI-CHAMPA; M. & T. MANO-RANJINI; M'. HIRWA CHAPHA; O. CHINI-CHAMPA; P. CHAMPA; T'. MANORANJITHAM

Artocarpus integrifolia (jack tree)= A. KOTHAL; B. KANTHAL; G. MAN-PHANASA; H. KATAHAR; M. & T. PILA; M'. PHANAS; O. PANASA; P. KATAR

Artocarpus lakoocha (monkey jack) =A. CHAMA, DEWA; B. DEO, DEO-PHAL; H. DEOPHAL, BARHAL; M'. LAKUCH; O. JEUTA; P. DEHEO

Asparagus racemosus=A. SHATMUL; B. SATAMULI; H. & P. SATAWAR; O. CHHATUARI; M., M'. & T. SATHAVARI; T'. SADAVARI

Averrhoa carambola=A. KORDOI-TENGA; B. KAMRANGA; G. KAMA-RAKHA; H. & P. KAMRAKH; M. IRIMPANPULI; M'. CAMARANGA; O. KARMANGA; T. KAMARANKAI; T'. TAMARTA

Azadirachta indica (margosa) = A. MOHA-NIM; B., H. & P. NIM, NIMBA; G. LIMBA; M. VEPPU; M'. KADU LIMB; O. NIMBA; T. VEMBU; T'. VEPPAI

Baccaurea sapida = A. LETEKU; B. LATKAN; H. LUTKO; P. KALA BOGATI

Balanites sp. = A. HINGOOL; B. HINGAN; G. HINGER; H. & P. HINGOL, HINGU; M. NANJUNTAI; M'. HINGANBET; O. HINGU; T. NANJUNDAN

Bambusa tulda (bamboo)=A. BANH; B., H. & P. BANS; G. KAPURA; M. MULAH; M'. BAMBOO; O. BAUNSA; T. MULAI

Barleria prionitis=A. NIL BAGI; B. KANTA-JHANTI; G. KANTAASHERIO; H. VAJRADANTI; M. KAVAKAM-BARAM; M'. KORANTI; O. DASKA-RANTA; P. PILA BANSA, GAT SARIYA; T. CHEMMULLI

Barringtonia acutangula=A. HIDGLI; B. & H. HIJAL; G. SAMUDAR-PHAL; M. & T. SAMUNDRAKKADAMI; M'. DHATRIPHAL; O. NIJALA; P. SAMUNDARPHAL

Basella rubra (Indian spinach)=A. PURAI; B. PUIN; H., O. & P. POI; M. SAMPARCHEERA; M'. VELBONDI; T. SAMBARKEERAI

Bassia latifolia = A., B. & H. MAHUA; G. MAHUDA; M'. MOHA; O. MAHULA; P. MOHWA; T. ILLUPPAI; T'. IPPA

Batatas edulis (sweet potato) = A. & B. MITHA-ALOO; G. SHAKKARIA; H. & P. SHAKARKAND; M. MADHURAKI ZHANGU; M'. RATALA; O CHINI-ALOO, KANDAMULA; T'. GENUSU

Bauhinia variegata (camel's foot tree)=A., B. & M'. KANCHAN; G KOVIDARA; H. & P. KACHNAR; M. MANDARUM; O. KANCHANA, T'. TIRUVATTI; T'. ADAVIMANDARA

Benincasa cerifera (ash gourd) = A. KOMORA; B. CHAL-KUMRA; G. KOHWLA; H. & P. PETHA; M. KUMPALAM; M'. KOHALA; O. PANIKAKHARU; T. KUMPALY; T'. PULLA GUMMUDI

Beta vulgaris (beet) = A. BEETPALENG; B. PALANG-SAK; G. & M'. BEET; H. & P. CHUKANDAR; O. PALANGA SAGA, BEET

Biophytum sensitivum (sensitive wood-sorrel)=A. & B. BAN-NARANGA; G. JAHARERA; H. LAJALU; M. MUKKUTTI, THINDANAZHI; M'. LAJARI

Blumea lacera = A. KUKUR-SHUTA; B. KUKUR-SONGA; G. KALARA; H. & P. KOKRONDA; M'. BURANDO; O. POKASUNGA; T KATUMULLANGI

Boerhaavia diffusa = A. PONONUA; B. & M'. PUNARNAVA; G. GHETULI; H. THIKRI, GADHAPURVA; M. THAZHUTHAMA; O. GHODAPURUNI; P. BISKHAPRA, ITSIT; T. MUKKARATAI; T'. PUNARNABA

Bombax malabaricum (silk cotton tree)=A. SIMALU; B. SIMUL; G. RATOSHEMALO; H. & P. SIMAR, SIMBAL; M. & T. ELAVU, MULLILAVU; M'. KATE SAVAR; O. SIMULI; T'. KONDABURAGA, SALMALI

Borassus flabellifer (palmyra-palm) =A. & B. TAL; G. & M'. TAD; H. & P. TAR; M. KARIMPANA; O. TALA; T. PANAI; T'. THADI

Boswellia serrata (incense tree) = A. DHUNA; B. DHUP, GUGGUL; G. DHUP-GUGALI; H. GUGUL; M. MUKUNDAM; M'. DHUP; P. SALAI, SALER; T. ATTAM; T'. ANDUGA

Brassica campestris (mustard) = A. SARIAH; B. SARISHA; G. SAFEDRAI; H. & P. SARSON; M. KATUKU; M'. MOHORI; O. SOROSHA; T. KARUPPUKKADUGU

Bryophyllum pinnatum (sprout-leaf plant)=A. PATEGAZA, DUPORTENGA; B. PATHURKUCHI; H. ZAKHM-I-HAYAT; M'. PANPHUTI; O. AMARPOI; P. PATHUR-CHAT; T. RANAKALLI; T'. SIMAJAMUDU

Butea monosperma (flame of the forest or parrot tree)=A., B. & M'. PALAS; G. KHAKARA; H & P. DHAK; M. CHAMATHA; O. PALASA; T. SAMITHU, PALASAM; T' MODUGA

Caesalpinia bonducella (fever nut) =A. LETAGUTI; B. NATA; G. KAKACHIA, H. KATKARANGA; M. KAZHANCHIKKUROO; M' SAGARGOTA; O. GILA; P. BEL KARANJWA; T KALAKKODI

Caesalpinia pulcherrima (dwarf gold mohur or peacock flower) = A. SWARNAKANTI; B. RADHACHURA; G SANDHESHARO; H GULETURA; M. RAJMALLI; M'. SHANKASUR; O. KRUSHNACHUDA, GODIBANA; P. KRISHANACHURA; T. MAYIRKONRAI; T'. TURAYI

Caesalpinia sappan (sappan or Brazil wood)=B., H. & P. BAKAM; G. PATANG; M. PATRANGAM; M'. PATANG; T. PATANGAM; T'. PATANGA

Cajanus cajan (pigeon pea) = A. RAHAR-MAH; B. ARAHAR; G. TUVARE; H. RAHAR; M. THUVARA; M'. TUR; O. HARADA; T. THOVARAY; T'. KANDULU

Calamus viminalis (cane) = A. BAT; B., H. & P. BET; M. CHOORAL; M'. VET; O. BETA; T. SURAL

Calophyllum inophyllum (Alexandrian laurel)=B. & H. SULTANACHAMPA, PUNNAG; M. & P. PUNNA; M'. UNDI; O. POLANGA; T. PUNNAGAM; T'. PUNNAGA

Calotropis gigantea (madar) = A. AKON-GOCH; B. AKANDA; G. AKADO; H. & P. AK; M. & T. ERUKKU; M'. RUI; O. ARKA; T'. JILLEDU

Canavalia gladiata (sword bean) = A. KANTAL-URAHI; B. MAKHANSHIM; H. BARA-SEM; M. & T. VAALAVARAKKAI; M'. ABAI; O. BADA SIMBA, MAHARADA; P. BARASEM, TALWAR PHALI; T'. TUMBATTAN KAYA

Canna indica (Indian shot) = A. PARIJAT-PHUL; B. & O. SARBAJAYA; G. KARDALI; H. SABBAJAYA; M. KATTUVAZHA; M'. KARDAL; P. HAKIK; T. KALVAALAI

Cannabis sativa (hemp)=A., B., H. & P. bhang, ganja; G., P. & T.

GANJA; M. KANCHAVU; M'. BHANG; O. BHANGA, GANJEI; T'. GANJA CHETTU

Capparis sepiaria = B. KANTA-GUR-KAMAI; G. KANTHARO; H. HIUN; M. THORATTI; M'. BASHINGI, KAKADANI; O. KANTIKAPALI; P. HIUS, HIUNGARNA; T. KARINDU; T'. NALLUPPI

Capsicum frutescens (chilli) = A. JOLOKIA; B. LANKA, MARICH; G. LALMIRICHI; H. & P. LAL-MIRCH; M. MULAGU; M'. MIRCHI; O. LANKAMARICHA; T. MILAGU; T'. MIRAPAKAYA

Cardiospermum halicacabum (balloon vine) = A. KOPALPHOTA; B. KAPALPHUTKI, SHIBJHUL; G. KARODIO; M. VALLIYUZHINJA; M'. KAPALPHODI; O. PHUTPHUTKIA; P. HAB-UL-KULKUL; T. MODAKATHAN; T'. BUDDAKAKKIRA, KASARITIGE

Carica papaya (papaw) = A. AMITA; B. PAYPAY; G. PAPAYI; H. & P. PAPITA; M. KARUTHA; M'. POPAI; O. AMRUTABHANDA; T. PAPALI; T'. BOPPAYI

Carissa carandas = A. KORJA-TENGA; B. KARANJA; H. & P. KARONDA; M. ELIMULLU; M'. KARVANDA; O. KHIRAKOLI; T. KALAKKAI; T' KALIVI

Carthamus tinctorius (safflower) = A. & B. KUSUM-PHUL; G. KUSUMBO; H. & P. KUSAM; M. SINDOORAM; M'. KARDAI; O. KUSUMA; T. & T'. KUSUMBA

Carum copticum = A. JONI-GUTI; B. JOWAN; G. AJAMO; H. & P. AJOWAN; M. AYAMODAKAM; M'. OWA; O. JUANI; T. OMAM; T'. OMAMU

Cassia fistula (Indian laburnum) = A. SONARU; B. SHONDAL; G. GARMALA; H. & P. AMALTASH; M. & T. KONNAI; M'. BAHAWA; O. SUNARI.

Cassia sophera = A. MEDELUA; B. KALKASUNDE; G. KASUNDARI; H. & P. KASUNDA; M. PONNARAN or PONNAM-THAKARA; M'. KALA-KASBINDA, O. KUSUNDA; T. PONNAVEERAN

Cassytha filiformis = B. AKASH-BEL; H. AMARBELI; M. AKASAVALLI; M'. AKASHVALLI; O. AKASHA BELA; P. AMIL, AMARBELI

Casuarina equisetifolia (beef-wood tree) = A., B., H & P. JHAU; G. VILAYATI SARU; M. CHOOLAMARUM, KATTADIMARUM; M'. KHADSHERANI; O. JHAUN; T. SAVUKKU; T'. SARAVU

Cedrela toona (toon) = B., H. & P. TOON; M. CHUVANNAGIL; M'. MAHANIM; T. MALAVEMBU; T'. GALIMANU

Celosia cristata (cock's comb) = A. KUKURA-JOA-PHUL; B. MORAGPHUL; G. LAPADI; H. JATADHARI; M. KOZHIPULLU; M'. KOMBADA; O. GANJACHULIA; P. KUKUR-PHUL

Centella asiatica (Indian pennywort) = A. MANIMUNI; B. THULKURI; G. KARBRAHMI; H. & P. BRAHMI-BOOTI; M. KODANGAL; KOTAKAN; M'. BRAHMI; O. THALKUDI; T. VULLARAI

Cestrum nocturnum (queen of the night) = A. & B. HAS-NA-HANA; H. HASN-I-HENA

Chenopodium album = A. JILMIL-SAK; B. & H. BATHUA-SAK (-g); G. CHEEL; M'. CHAKAVAT; O. BATHU SAGA; P. BATHU; T. PARUPUKKIRAI

Chrysanthemum coronarium = A. & B. CHANDRA-MALLIKA; G. & H. GULDAUDI; M. SHEVANTI; O. SEBATI; P. GUL-DAUD; T. SHAMANTIPPU; T'. CHAMANTI

Chrysopogon aciculatus (love thorn) = A. BON-GUTI; B. CHOR-KANTA; O. GUGUCHIA; P. CHOR-KANDA

Cicer arietenum (gram) = A. BOOTMAH; B. CHHOLA; G., H. & P. CHANA; M. & T. KADALAI; M'. HARABHARA; O. BUTA; T'. SANIKALU

Cinnamomum camphora (camphor) = A. & B. KARPUR; G., H. & M'. KAPUR; M. KARPPURAVRIKSHAM; O. KARPURA; P. KAFUR; T. KARUPPURAM; T'. KAPPURAMU

Cinnamomum tamala (bay leaf) = A. TEJPAT, MAHPAT; B. TEZPATA; G. & H. TEZPAT; M'. TAMAL; O. & P. TEJPATRA; T. TALISHAPPATTIRI; T'. TALLISHAPATRI

Cinnamomum zeylanicum (cinnamon) = A., B., G., M'., O. & P. DALCHINI; H. DARCHINI; M. & T. ILLAVANGAM; T'. LAVANGAMU

Cissus quadrangularis = A., B. & H. HARIJORA; M. PIRANTA; M'. KANDAWEL; O. HADAVANGA; P. GIDAR-DAK, DRUKRI; T. PIRANDAI; T'. NALLERU

Citrullus colocynthis (colocynth) = A. KOABHATURI; B. MAKAL; G. & H. INDRAYAN; M. & T. KUMMATHIKKAI, PEYKUMMATTI; M'. KAVANDAL; O. INDRAYANA; P. TUMMA; T'. PATSAKAYA

Citrullus vulgaris (water melon) = A. KHORMUJA; B. TARMUZ; G. KARIGU; H. & P. TARBUZA; M. & T. KUMMATTIKKAI; M'. KALINGAD; O. TARABHUJA

Citrus aurantifolia (sour lime) = A. NEMU-TENGA; B. KAGJI-NEBU; G. LIMBU; H. NIMBOO; M. CHERU-NARAKAM; M'. KAGADI LIMBU; O. LEMBU; P. GALGAL; T. ELIMICH-CHAM; T' NIMMAPANDU

Citrus reticulata (orange) = A. KAMALA-TENGA; B. KAMALA; G SUNTRA; H. NARANGI; M. NARA-KAM; M'. SANTRA; O. KAMALA; P. SANGTRA; T. NARANGAM; T'. NARANJI

Citrus grandis (pummelo or shaddock) = A. REBAB TENGA; B. BATABI-NEBU; G. OBAKOTRU; H. & P. CHAKOTRA; M. BAMBLEENARAKAM; M'. PAPANAS; O. BATAPI; T BAM-BALMAS

Clerodendron infortunatum = A. BHET-TITA; B. & H. BHANT, GHENTU; M. PERU-VALLEM; G. & M'. KARI; O. KUNTI; P. KARU; T. KARUKANNI; T'. BASAVANAPADU

Clitoria ternatea (butterfly pea) = A, B. & O. APARAJITA; G. GARANI; H. APARAJIT; M. SANKHU-PUSH-PAM; M'. GOKARNA; P. APARAJIT, NILI LOEL; T. KAKKATAN; T'. SANGA-PUSHPAM

Coccinia cordifolia = A. BELIPOKA; B TELAKUCHA; H. BHIMBA; M. KOVEL; M'. TONDALE; O. KUN-DURI, KAINCHIKAKUDI; P. GHOL; T. KOVARAI; T'. KAKIDONDA

Cocos nucifera (coconut-palm) = A. NARIKOL; B. NARIKEL; G., H. & P. NARIYAL; M. THENGU, NALI-KERAM; M'. NARAL; O. NADIA; T. THENGU; T'. TENKAYA

Coix lachryma-jobi (job's tears) = A. KAURMONI; B. KALA-KUNCH, GURGAR; G. KASAI; H. SANKRU; M'. RAN JONDHALA; O. GARAGADA; P. KALA-KUNCH; T. KATTU KUNDU-MANI

Colocasia esculenta (taro) = A. & B KACHU; H. & P. KACHALU; M. CHEMPU; M'. KASALU; O. SARU; T. SAMAKILANGOO; T'. CHEMA

Commelina bengalensis = A. KONASI-MOLU; B. KANSHIRA; G. MHOTUN-SHUSHMULIYUN; O. KANSIRI

Coriandrum sativum (coriander) = A., B., H., O. & P. DHANIA; G DHANE; M. & T. KOTTAMALLI; M'. KOTHIMBIR; T'. DHANIYALU

Crataeva religiosa = A. & B. BARUN; G. VAYAVARNA; H. & P. BARNA; M. NIRMATHALAM; M'. WAYA-WARNA; O. BARUNA; T. MAVA-LINGAM; T'. VOOLEMERI

Crinum asiaticum = B. & P. SUKH-DARSHAN; M. POLA-THALI; G. & & M'. NAGDAUNA; O. ARISA; T. VESHA-MOONGHEE

Crocus sativus (saffron) = A., B. & O. JAFRAN; G. & M'. KESHAR; H. & P. ZAFRAN; T. KUNGUMAPU; T'. KUNKUMAPAVE

Crotalaria juncea (Indian hemp) = A. SHON; B. SHONE; G, H. & P. SAN; M. THANTHALAKOTTI; M'. KHULKHULA; O. CHHANAPATA; T. SANAPPAI; T'. JANNAMU

Crotalaria sericea (rattlewort) = A. GHANTA-KORNA; B. ATASHI; H. JHUNJHUNIA; M. THANTHALAKOTTI; M'. GHAGRI; O. JUNKA; P. JHAN JHANIAN

Croton tiglium = A. JOYPAL; B JAI-PAL; G JAMAL GOET; H., M'. & P. JAMALGOTA; M. & T. NIRVALEM; O. BAKSA GACHHA

Cucumis melo (melon) = A. BANGI; B. PHUTI; G. TARBUCH; H. & P. KHARBUZA, PHUTI & KAKRI; M. & T. THANNIMATHAI; M'. KHARBUJ; O. KHARBUJA

Cucumis sativus (cucumber) = A. TIANH; B. SASHA; G. KAKRI; H., M'. & P. KHIRA; M. MULLEN-VELLARI; O. KAKUDI; T. MULLU-VELLARI

Cucurbita moschata (sweet gourd) = A. RONGA-LAU; B. MITHA-KUMRA; H. MITHA-KADDU; M. MATHANGAI; M'. KALA BHOPALA; O. MITHA KOKHARU; P. HALWA-KADDU; T. POOSANIKAI

Curcuma amada (mango ginger) = A. & B. AMADA; G. AMBA-HALDAR; H. AM-HALDI; M'. AMBE HALAD; O. AMBA KASSIA ADA; P. AMBA HALDI; T'. MAMIDIALLAM

Curcuma domestica (turmeric) = A. HOLODHI; B. HALOOD; G. & M'. HALAD; H. & P. HALDI; M. KUVA; O. HALADI; T. MANJAL; T'. PASUPU

Cuscuta reflexa (dodder) = A. AKASHI LOTA, RAVANAR-NARI; B. SWARNA-LATA; G. AKASWEL; H. AKASH-BEL; M'. AMAR VEL; O. NIRMULI; P. AMARBEL

Cynodon dactylon (dog grass) = A. DUBORI-BON; B. DURBA-GHAS; G. DURVA; H. & P. DOOB; M. & T. ARUGAMPULLU; M'. HARALI; O. DUBA GHASA; T'. GERICHA GADDI

Cyperus rotundus (sedge) = A. MOTHA; B. & H. MUTHA; G. BARIK-MOTHA; M. KORA; M'. & P NAGAR-MOTHA; O. MUTHA GHASA; T. KORAI; T'. PURA GADDI

Dalbergia latifolia (Indian rosewood) = B. SITSAL; G. SISAM; M. & T. ITTI; M'. SISSU; O. PAHADI SISU; T'. JITTEGI

Dalbergia sissoo (Indian redwood) = A SHISHOO; B. SISSOO; G SHISHAM; H. & P. SHISHAM, TAHLI; M. VEETI; M'. SHISAVI; O SISU

Datura fastuosa (thorn-apple) = A. DHOTURA; B. DHUTRA; G DHATOORA; H. & P. DHUTURA; M UMMAM; M'. DHOTRA; O. DUDURA; T. OOMMATHAI; T'. UMMATHA

Delonix regia (gold mohur) = A. & B. KRISHNACHURA; G., H., M'. & P. GULMOHR; M. MARAMANDARAM; O. RADHACHUDA; T. MAYILKONNAI

Desmodium gangeticum = B. SALPANI; G SALVAN; H. SALPAN; M. PULLATI; M'. SALPARNI; O. KURSOPANI; P. SHALPURNI; T. PULLADI; T'. GITANARAM

Desmodium gyrans (Indian telegraph plant) = A. & B. BAN-CHANDAL, GORACHAND; H. BAN-CHAL; O GORA CHANDA, TELEGRAPH GACHHA; P. PAUDA TAR

Dillenia indica = A. OU-TENGA; B., H & P. CHALTA; G. CARAMBAL; M. VALLAPUNNA; M'. KARAMAL; O. OU; T. UVATTEKU; T'. UVVA

Dioscorea alata (white yam) = A. KATH-ALOO, PATNI-ALOO; B. & H. CHUPRI-ALOO, KHAM-ALOO; M'. KONA; O. KHAMBO-ALOO; P. KNISS; T. KAYAVALLI; T'. GUNAPENDALAMU

Dioscorea bulbifera (wild yam) = A. GOCH-ALOO; B. GACHH-ALOO; G. SAURIYA; H. & P. ZAMINKHAND; M. KATTUKACHIL; M'. KADU KARANDA; O. DESHI-ALOO, PITA ALOO; T. KATTUKKILANGU; T'. CHEDUPADDUDUMPA

Diospyros ebenum (Indian ebony) = B. ABLOOSH; H. TENDU; M. KARU; M'. & P. ABNUS; T. KARKAYTTALI; T'. NALLAVALLUDU

Diospyros embryopteris (wild mangosteen) = A. & O. KENDU; B. & P. GAB; G. TEMBU; H. TENDU; M. VANANJI; M'. TEMBURNI; T. TUVARAI; T'. TUMMIKA

Dolichos lablab (country bean) = A. UROHI; B. SHIM; G. AVRI; H. & P. SEM; M. SIMA-PAYARU; M'. PAVATA, VAL; O. SIMA; T. AVARAI; T'. CHIKKUDI

Duranta plumieri = A. JEORA-GOCH; B. DURANTA-KANTA; H. & P. NILKANTA; M'. DURANTA; O. BILATI KANTA, BENJUATI

Ecbolium linneanum = B. NILKANTHA; H. & P. UDAJATI; M. KURANTA; M'. RAN ABOLI; O. NILAKANTHA; T. NILAMBARI

Eclipta alba = A. KEHORAJI; B. KESARAJ; G., H. & P. BHANGRA; M. & T KAYYANYAM, KAITHONNI; M'. MAKA; O. KESHDURA

Elephantopus scaber (elephant's foot) = B. & H. HASTIPADA, GOBHI; G. BHOPA THARI; M. & T. ANACHUVADI; M'. HASTI PAD; O. GOBI; P. GAOZBAN

Eleusine coracana = B. & H. MARHUA; G. NAVTO; M. PANJAPPULLU; M'. NACHANI; O. MANDIA; P. KODRA, MANDWA; T. KOLVARAKU; T'. RAGI

Enhydra fluctuans = A. HELACHI-SAK, MONOA-SAK; B. & P. HALENCHA; H. HARUCH; M'. HARKUCH; O. HIDIMICHI, PANI SAGA

Entada scandens (nicker bean) = A. GHILA; B., H., O. & P. GILA; G. SUVALI-AMLI; M. KAKKUVALLY; M'. GARBI; T. CHILLU; T'. GILLATIGAI

Enterolobium saman (rain tree) = A. SIRISH GOCH; M. URAKKAM-THOONGIMARAM; M' SAMAN; O. BADA GACHHA CHAKUNDA, BANA SIRISHA

Ervatamia divaricata = A. KOTHONAPHUL; B & M'. TAGAR; H. & P. CHANDNI; M. & T. NANTHIAR VATTAM; O. TAGARA

Erythrina indica (coral tree) = A. MODAR; B. MANDAR; G. PANARAWAS; H. PANJIRA; M. & T. MURUKKU; M'. PANGARA; O. PALDHUA; P. DARAKHT FARID, PANGRA

Euphorbia antiquorum = B. BAJBARAN; G. TANDHARI; M. CHATHIRAKKALLI; M'. CHAUDHARI NIWDUNG; O. DOKANA SIJU; P. DANDA THOR; TIDHARA SEHUD; T'. SHADRAKALLI; T'. BONTHAKALI

Euphorbia neriifolia = A. SIJU; B. MANSHA-SIJ; G. THOR; H. SIJ; M. & T. ILAKKALLI; M'. CHAUDHARI NIWDUNG; O. PATARA SIJU; P. CANGICHU; T'. AKUJEMUDU.

Euphorbia nivulia=A. SIJU; B. SIJ; G. THOR KANTALO; H. SIJ, THOR; M. & T. ILAKKALLI; M'. NIWDUNG; O. SIJU; T'. AKUJEMUDU

Euphorbia pulcherrima (poinsettia) =A. LAL-PAT; B., M'. & P. LAL-PATA; O. PANCHUTIA; P. LAL-PATTI; T. MAYILKUNNI

Euryale ferox=A. NIKORI; B., H. & P. MAKHNA; M'. PADMA KANT, MAKHAN; O. KANTA PADMA

Evolvulus alsinoides = G. JHINKI-PHUDARDI; H. SHYAMAKRANTA; M. VISHNUKTANTHI, KRISHNAKTANTHI; M'. VISHNU KRANT; O. BICHHA-MALIA; P. SHANKH-HOLI; T. VISHNUKIRANDI; T'. VISHNU-KRANTHI

Ferula foetida (asafoetida)=A., B., G., H., M'. & P. HING; M. KAYAM; O. HENGU

Ficus benqalensis (banyan)=A. BOR-GOCH; B. BOT; H. & P. BARH; G. & M'. WAD; M. PEERALU; O. BARA; T. AALUMARAM; T'. MARRI

Ficus glomerata (fig)=A. DIMORU; B. DUMUR; G. UMBARO; H & P. GULAR; M. & T. ATHTHYMARAM; M'. UMBAR; O. DIMURI; T'. BODDA

Ficus religiosa (peepul)=A. ANHOT; B. ASWATTHA; G. JARI; H. & P. PIPAL; M. ARAYALU; M'. PIMPAL; O. ASWATHA; T. ARASU; T'. ASWATHAM

Flacourtia cataphracta=A. PONIAL; B. & H. PANIALA; G. TALISPATRA; M. & T. TALISAM; M'. JUGGUM; O. PANIONLA; P. PANIALA, PANI-AUNLA; T'. TALISAPATRAMU

Flacourtia ramontchi = B. BOINCHI; H. BOWCHI, BILANGRA; M'. BHEKAL; O. BAINCHA KOLI; P. KATAI, KUKAI; T. MALUKKARAI; T'. KANAREGU

Foeniculum vulgare (anise or fennel) =A. GUA-MOORI; B. PAN-MOURI; G. WARIARI; H. & P. SAUNF; M'. BADISHEP; O. PAN MOHURI

Garcinia mangostana (mangosteen) =B., H. & M'. MANGUSTAN; G. MANGOSTEEN; M. SULAMPULI; O. MANGOSTEEN, SITAMBU; T. SULAM-BULI

Gardenia florida (cape jasmine)=A. TOGOR; B., H. & P. GANDHA-RAJ; G. DIKAMALI; M'. GANDH-RAJ; O. SUGANDHARAJ

Giardinia zeylanica = A. SHORU-CHORAT; B. BICHUTI, M AANA-CHORIYANAM; O. BICHHUATI; P. BICHUTI, BHABHER

Gloriosa superba (glory lily)=A. & B ULAT-CHANDAL, G. & M'. KHADYANAG; H. KALIARI, KULHARI; M. MANTHONNI, PARAYANPOOVA; O. PANCHAANGULIA, P. GURHPATNI, KULHARI; T KALAPAI-KILANGU; T. AGNISIKA

Glycosmis arborea=A. CHAUL-DHOA; B. ASHHOURA; H. BANNIMBU; M. PANAL; O. CHAULADHUA

Gossypium herbaceum (cotton)=A. KOPAH; B., H & P KAPAS; G. RUI; M. KURUPARATHY; M' KAPUS; O. KAPA; T PARATHY

Gyanadropsis gynandra=A. BHUT-MULA; B. HURHURE; G. ADIYA-KHARAM; H. HURHUR; M. KATTU-KATUKU; M'. TILVAN; O ANASO-RISIA, SADA HURHURIA; P. HUL-HUL; T. NAIKADUGU; T'. VAMINTA

Helianthus annuus (sunflower) = A. BELI-PHUL; B & O. SURJYAMUKHI; G. SURYAMUKHI; H. & P. SURAJ-MUKHI; M., T. & T' SURIYA-KANTI; M'. SURYAPHUL

Heliotropium indicum (heliotrope)= A. & B. HATISUR; G. HATHISUN-DHANA; H. HATTASURA; M. TEKKADA; M'. BHURUNDI; O. HATI-SUNDA. P. UNTH-CHARA

Hemidesmus indicus (Indian sarsaparilla)=A & B ANANTAMUL; G. DURIVEL; H. SALSA; M'. ANANT-MUL; O. ANANTAMULA, KAPRI; P. DESI BARVA; T. NANNARI; T'. SUGANDIPALA

Hibiscus cannabinus (Madras or Deccan hemp)=B. NALITA; G. BHINDI; H. AMBARI; M. KANJARU; M'. AMBADI; O. KAUNRIA, NALITA; P. SAN-KUKRA; T. KACHURAI

Hibiscus esculentus (lady's finger)= A., O. & M', BHENDI; B., H. & P. BHINDI; G. BHINDA; M. & T. VENDAKKA; T'. BENDA

Hibiscus mutabilis=A. & B. STHAL PADMA; G. UPALASARI; H. GULI AJAIB; M. CHINAPPARATTI; M'. GULABI BHENDI; O. THALAPADMA; P. GUL-I-AJAIB; T. SEMBARATTAI

Hibiscus rosa-sinensis (China rose or shoe-flower)=A. JOBA; B. JABA; G. JASUNT; H. GURHAL, JASUM; M. CHEMPARATHY; M'. JASWAND; O. MANDARA; P. GURHAL JIA PUSHPA; T. SAMBATHOOCHEDI; T'. DASANI

Hibiscus sabdariffa (rozelle) = A. MESEKA-TENGA; B. MESTA; H. & P. PATWA; M. PULICHI; M'. LAL-AMBADI; O. KHATA KAUNRIA

Hiptage madablota = A. MADHOI-LOTA; B. & O. MADHABI-LATA; G. MADHAVI; H. MADHU-LATA; M. SITAPU; M'. MADHUMALATI; P. MADHULATA, BANKAR; T. KURUK-KATTI, MADAVI

Holarrhena antidysenterica = A. DUD-KHORI; B. KURCHI; G. INDRA-JAVANU; H. KARCHI; M. KODA-KAPPALA; M'. KUDA; O. PITA KORUA; P. INDER JAU, KAWAR

Hordeum vulgare (barley) = A. & B. JOB; G. BAJRI; H. JAWA; M'. SATU; O. BARLEY, JABA; P. JAU; T. BARLIYARISI; T. YAVAKA

Hygrophila spinosa = B. KULEKHARA; G. EKHARO; H. GOKULA-KANTA; M'. KOLSHINDA; O. KANTAKALIA, KOILIKHIA; P. TALMAKHANA; T. NIRMULLI

Impatiens balsamina (balsam) = A. DAMDRUKA; B. DOPATI; H. GUL-MENDI, M. & T. BALSAM; M'. TERADA; O. HARAGOURA; P. MA-JITI, BANTIL, PALLU

Indigofera tinctoria (indigo) = A, B., H. & P. NIL; G. GALI; M. AMARY; M. NEEL; O. NILA; T. AVARY; T. AVIRI

Ipomoea reptans (water bindweed) = A. KALMAU; B. & H. KALMI-SAK (-G); G NALINIBHAJI; M'. KALAMBI, NAL; O. KALAMA SAGA; P. NALI, KALMI SAG

Ipomoea pes-tigridis = B. LANGULI-LATA; M. VELLATAMPU; O. KAN-SARINATA, P. ISHOPECHAN

Ixora coccinea = A. & B. RANGAN; H. GOTAGANDHAL; M. & T. CHETHTHY, THETTY; M'. MAKADI; O. KHADIKA PHULA, RANGANI; P. RUNGAN

Jasminum sambac (jasmine) = A. JUTI-PHUL; B. & H. BELA; G. BAT-MOGRI; M. MULLA; M'. MOGARA; O. MALLI

Jatropha curcas (physic or purging nut) = A. BONGALI-ARA; B. BAGH-BHARENDA; G. JEPAL; H. JANGLI-ARANDI; M. KATALAVANAKKU; M'. MOGALI ERAND; O. BAIGABA; P. JAMALGOTA, JABLOTA, JAPHROTA

Jatropha gossypifolia = A. BHOT-ERA; B., H. & P. LAL-BHARENDA; M'. VILAYATI ERAND; O. NALI BAIGABA, VERENDA; T. ADALAI; T'. NEPALEMU

Jussiaea repens = A. TALJURIA; B. KESSRA; M. NIRGRAMPU; M'. PAN LAWANG; T. NIRKIRAMPU; T' NIRUYAGNIVENDRAMU

Lagenaria siceraria (bottle gourd) = A. JATI-LAU; B. & O. LAU; H. LAUKI; M. & T. CHORAKKAI; M'. DUDHYA BHOPALA; P. GHIYA

Lagerstroemia flos-reginae = A. AJAR; B., H. & P. JARUL; M. NIRVEN-TEKKU; M'. TAMAN; O. PATOLI; T. PUMARUTHU

Lantana indica (lantana) = G. GHANI-DALIA; M. PUCHEDI: M'. GHA NERI; O. NAGA-AIRI; P. DESI LAN-TANA; T. ARIPPU; T'. LANTANA

Laportea crenulata (devil or fever nettle) = A. DOM-CHORAT; M. CHO-RITANAM; M'. & P. CHORPATTA; T'. OTTAPILAVU

Lathyrus aphaca (wild pea) = A. & B. BAN-MATAR; G. JANGLI VATANA; H. JANGLI-MATAR; M'. VAN-MATAR; O. JANGALI MATAR; P. JANGLI MATAR, RAWARI

Lathyrus sativus = A. KOLA-MAH; B., H. & O. KHESARI; G. MATER; M'. LAKH; P. KISARI DAL

Lemna paucicostata (duckweed) = A. SORUPUNI; B. KHUDI-PANA; M'. TIKLICHE SHEWALE; O. CHU-NIDALA, BILATI DALA; P. BUR

Lens culinaris (lentil) = A. MOSOOR-MAH; B. MASURI; G. MASURIDAL; H., M'. & P. MASUR; O. MASURA

Leonurus sibiricus = A. RONGA-DORON; B. DRONA; H. HALKUSHA, GUMA; O. BHUTA-AIRI, KOILIKHIA

Lepidium sativum (garden cress) = A. & B. HALIM-SAK; G. ASALIYA; H. HALIM; M' ALIV; O HIDAMBA SAGA; P. HALON

Leucas linifolia = A. DORON, DURUM-PHUL; B. SWET-DRONA; G. JHINA-PANNI KUBO; H. CLOTA-HALKUSA; M. THUMPA; M'. DRONAPUSHPI, GUMA; O GAISA; P. GULDODA; T. THUMBAI; T'. TAMMA CHETTU

Limonia acidissima (elephant-apple) = A. & B KATH-BAEL; G. KOTHA; H. & P. KAITHA; M. BLANKA; M'. KAWATH; O. KAINTHA; T. VELAMARUM; T'. VELANGA

Linum usitatissimum (linseed) = A. TICHI; B. TISHI; G. JAVA; H. & P. ALSHI; M'. JAWAS; O. PESI; T. AALI-VIRAI

Loranthus longiflorus=A. ROGHU MALA; B. MANDA; G. VANDO; H. BANDA; M. ITHTHIL; M'. BAND GUL; O. MALANGA, MADANGA; P PAND; T. PULLURUVI; T'. BAJINNIKI, BADANIKA

Luffa acutangula (ribbed gourd)=A. JIKA; B. JHINGA; G. SIROLA; H. & P. KALI-TORI; M PEECHIL. PEECHINGAI; M'. DODAKA; O. JAHNI; T. PEECHANKA

Luffa cylindrica (bath sponge or loofah)=A. BHOL; B. DHUNDUL, H. & P. GHIYA-TORI; M' GHOSALE; O. PITA TARADA

Lycopersicum esculentum (tomato)=A. BELAHI-BENGENA; B. BILATI-BEGOON; H. & P. TAMATAR; G. TAMETA, TOMATO, RAKTAVURNTANK; M. & T. THAKKALIKKAI; M'. TAMBETA; O. BILATI BAIGANA, T'. THAKKALI

Malva verticillata (mallow)=A. & B. LAFFA; H. & P. SONCHAL

Marsilea quadrifida=A. PANI-TENGECHI; B. SUSHNI-SAK; M. NALILAKKOTAKAN; O. SUNSUNIA; P. CHAUPATI; T. ARAKKODAI

Martynia diandra (tiger's nail)=A & B. BAGH-NAKHI; G. VICHCHIDA; H. SHERNUI; M. & T. KAKKACHUNDU, PULINAGAM; M. WINCHAURI; O. BAGHA NAKHI; P. HATHAJORI; T'. GARUDA MUKKU

Mesua ferrea (iron-wood)=A. NA HOR; B. NAGESWAR; H. NAGKESAR; M. & T. IRUMPARATHTHAN; M'. NAG-CHAMPAKA; O NAGESWARA; P. NAGAR KESAR; T'. NAGAKESARI

Michelia champaca = A. & P. CHAMPA-PHUL; B. SWARNACHAMPA; G. RAE CHAMPAC; H CHAMPAK; M. & T. CHEMPAKAM; M'. SONCHAPHA; O. CHAMPA; T' SAMPAKA

Millingtonia hortensis (Indian cork tree)=B, H., M. & P. AKASNIM; O. NIALI

Mimosa pudica (sensitive plant)=A. LAJUKI-LOTA; B. LAJJABATILATA; G. LAJJAWANTI; H. & P. LAJWANTI; M. THOTTALVADI; M' LAJALU; O. LAJAKULI, LAJKURI; T. THOTTASINIGI; T'. PEDDA NIDRAKANTHA

Mirabilis jalapa (four o'clock plant or marvel of Peru)=A. GODHULI-GOPAL; B. KRISHNAKOLI; H. GULABBAS; M. NALUMANICHEDI; M'. GULBAKSH; O. RANGANI, BADHULI; P. GUL-ABBASI; T. ANDIMANDARAI; T'. CHANDRAKANTA

Momordica charantia (bitter gourd)=A TITA-KERALA; B. KARALA & UCHCHE; G., H. & P. KARELA; M. & T. PAVAL, PAVAKKAI; M'. KARLE; O. KALARA; T'. KAKARA

Moringa oleifera (drumstick or horse radish)=A. & O. SAJANA; B. SAJINA; G. SARAGAVA; H. SAINJNA; M. MURINGA; M'. SHEVAGA; P. SAONJNA; T. MURUNGAI; T'. MUNAGA

Morus indica (mulberry) = A. NOONI; B. TOONT; G. TUTRI; H. & P. SHAH-TOOT; M. MALBERRY; M'. TUTI; O. TUTAKOLI

Mucuna pruriens (cowage)=A. BANDAR-KEKOA; B. ALKUSHI; G. KIVANCH; H. & P. KAWANCH; M. NAI-KORUNA; M'. KHAJ KUIRA; O. BAIDANKA

Murraya exotica (chinese box) = A. KAMINI-PHUL; B. & O. KAMINI; H. MARCHULA; M. MARAMULLA; M': PANDHARI KUNTI; P. MARUA; T. KATTUKARUVEPPILAI; T'. NAGAGOLUGI

Myristica fragrans (nutmeg)=B., H., M'. & P. JAIPHAL; G. JAYIPHAL; M. & T. JATHIKKAI; O. JAIPHOLO; T'. JAJIKAYA

Nelumbium speciosum (lotus) = A. PODUM; B. & O. PADMA; G. & M'. KAMAL; H. & P. KANWAL; M. THAMARA; T. THAMARAI; T'. TAMARA

Nerium indicum (oleander)=A. KORBI-PHUL; B. KARAVI; G. & M'. KANHER; H. & P. KANER; M. & T. ARALY; O. KARABI; T'. GANNERU

Nicotiana tabacum (tobacco)=A. DHOPAT; B. TAMAK; G., H., M'. & P TAMBAKU; M. & T PUKAYILA; O. DHUANPATRA; T'. POGAKU

Nigella sativa (black cumin)=B. & O. KALA-JIRA; G. KADU-JEEROO; H. KALOUNJI; M. & T. KARUNJIRAGAM; M'. KALA JIRE; P. KALONGI, KALA-JIRA

Nyctanthes arbor-tristis (night jasmine)=A. SEWALI-PHUL; B. SHEWLI, SHEPHALI; G. RATRANI; H. HARSHINGAR; M. PAVIZHAMULLA; M'. PARIJATAK; O. SINGADAHARA; P. HARSANGHAR; T. PAVELAM; T'. PARIJATHAM

Nymphaea lotus (water lily)=A. BHET; B. SHALOOK; G. NILOPAL; H. & P. NILOFAR; M. & T. AMPAL; M'. LAL-KAMAL; O. KAIN, KUMUDA

Ocimum sanctum (sacred basil)=A. TULASHI; B., G., H. & P. TULSI; M. & T. THULASI; M'. TULAS; O. TULASI; T'. ODDHI

Oldenlandia corymbosa=B. & P. KHETPAPRA; G. PARPAT; H. DAMAN-PAPPAR; M'. PITPAPADA; O. GHAR-PODIA

Opuntia dillenii (prickly pear)=A. SAGOR-PHENA; B PHANI-MANSHA; G. NAG-NEVAL; H. NAGPHANI; M. ELAKKALLI; M'. PHADYA · NIWDUNG; O. NAGAPHENI; P. CHITARTHOR; T. SAPPATHTHIKKALLI; T'. NAGADALI

Orobanche indica (broomrape)=B. BANIA-BAU; H. & P. SARSON-BANDA; T. POKAYILAI-KALAN

Oroxylon indicum=A. BHAT-GHILA; B. SONA; G. PODVAL; H. ARLU; M. PATHIRI; M'. TETU; O. PHANPHANIA, PHAPANI; P. SANNA; T. PAYYALANTHA; T'. PAMPINI

Oryza sativa (paddy)=A., B. & H. DHAN; G. CHOKHA; M. ARI; M'. BHAT; O. DHANA; P. CHAWAL; T. ARISHI; T'. URLU

Oxalis repens (wood-sorrel)=A. SENGAI-TENGA, TENGECHI; B. AMRUL-SAK; H. CHUKA-TRIPATI, KHATTI-PATTI; M. PULIYARILA; M'. AMBOSHI; O. AMBILITI, AMLITI; P. KHATTI-BUTI

Paederia foetida=A. BHEDAI-LOTA; B. GANDHAL; G. GANDHANA; H. GANDHALI; M. TALANILI; M'. PRASARUM; O. PASARUNI; P. GUNDALI; T'. SAVIRELA

Pandanus odoratissimus (screw-pine)=A. KETAKI-PHUL; B. & G. KETAKY; H. & P. KEORA; M. KAITHA; M'. KEWADA; O. KIA; T THAZHAI; T'. MOGIL

Panicum miliaceum (Indian millet) =B., H., O. & P. CHEENA; G. SAMLI; M. THENA; M'. WARAI; T. VARAGU; T'. VARAGI

Papaver somniferum (opium poppy)= A. AFU-GOCH; B. AFING; G. APHIM; H. & P. POST; M. & T. KASHAKASHA; M'. AFHU; O. APHIMA

Passiflora foetida (passion-flower)= A. JUNUKA; B., H. & P. JHUMKALATA; M. KRISTHUPAZHAM, M'. KRISHNA KAMAL; O. JHUMUKALATA; T. SIRUPPUNAIKKALI; T'. TELLAJUMIKI

Pedilanthus tithymaloides (jew's slipper)=B. RANG-CHITA; H. NAGDAMAN; M. VERAKKODI; M'.VILAYATI SHER; O. BILATI SIJU, CHITASIJU; P. NAG DAUN

Pennisetum typhoides (pearl millet) =B., H., O. & P. BAJRA; M. & T. KAMPU, BAJRA; M'. BAJARI; T'. SAJJA

Pentapetes phoenicea (noon flower) =B. DUPOHRIA; G. DUPORIO; H. GULDUPAHARIA; M'. DUPARI; O. DIPAHARIA; P. GULDUPAHARIA

Phaseolus aureus (green gram)=A. MOGU-MAH; B. & H. MOONG; G. MUGA; M. CHERUPAYARU; M'. HIRAVE MUG; O. JHAIN-MUGA; P. MUNG; T. PACHAPAYARU; T'. PESALU

Phaseolus mungo (black gram)=A. MATI-MAH; B. MASH, KALAI; G. UDAD; H. URID; M. UZHUNNU; M'. UDID; O. MUGA; P. MASH; T. ULUNNU; T'. UDDULU

Phoenix sylvestris (date palm)=A. & B. KHEJUR; G., H. & P. KHAJUR; M. ITTA; M'. KHARIK; O. KHAJURI; T. ICHCHAM; T'. ITHA

Phragmites karka=A. KHAGRA; B. & P. NAL; H. NUDA-NAR; O. JANKAI

Phyllanthus acidus=A. HOLFHOLI, PORAMLOKHI; B. NOAR; H. CHALMERI, HARFARAURI; M. NELLIPULI, ARINELLI; M'. RAY AWALI; O NARAKOLI; T. ARUNELLI; T'. RATSAVUSIRIKI

Phyllanthus emblica (emblic myrobalan)=A. AMLOKI; B. AMLA, AMLAKI; G. AMBALA; H. AMLIKA; M. & T. NELLIKKAI; M'. AWALA; O ANLA; P. AMLA; T'. USIRI

Piper betle (betel)=A., B., G., H. & P. PAN; M. & T. VETHILA; M'. NAGWELI; O. PANA; T'. TAMALAPAKU

Piper cubeba (cubeb)=B., H. & O. KABAB-CHINI; G. TADAMIRI; M. & T. THIPPLI; M'. KABAB CHINI, KANKOL; T'. TOKAMIRIYALU

Piper longum (long pepper)=A. PIPOLI; B. PIPOOL; G. PIPARA; H. PIPLI; M. THIPPALI; M'. PIMPALI; O. PIPALI; P. DARFILFIL, MAGHAN

Piper nigrum (black pepper)=A. JALUK; B. GOL-MARICH; G. KALO-MIRICH; H. GOLMIRCH; M. KURU-MULAGU; M'. KALI MIRI; O. GOLA MARICHA; P. KALI MARCH; T MILAGOO; T'. SAVYAMU

Pistia stratiotes (water lettuce)=A. BORPUNI; B. PANA; G JALAKUM-BHI; H. & P. JAL-KHUMBI; M MUTTAPPAYAL; M'. GANGAVATI; O BORA JHANJI; T. AGASATHAMARAI; T'. AKASATAMARA

Pisum sativum (pea)=A MOTOR, B H., O. & P. MATAR; G. VATANA, M PAYARU; M'. WATANE; T. PATTANI: T'. GUNDUSANIGHELU

Plantago ovata=A., B & O. ISOBGUL; G. UTHAMUJEERUM; H., M' & P. ISOBGOL; M. KARKATASRINGI, T'. ISHAPPUKOL

Plumbago zeylanica=A. AGYACHIT, B. CHITA; G. CHITRAMULA; H., M' & P. CHITRAK; M & T. KODU-VELI; O DHALACHITA

Plumeria rubra (pagoda tree)=A GULANCHI; B. KAT-GOLAP; G. RHAD CHAMPO; H. & P. GOLAINCHI; M EEZHAVA-CHEMPAKAM; M' KHUR CHAPHA; O. KATHA CHAMPA; P GULCHIN

Polanisia icosandra=B HALDE-HURHURE; G. TILVAN; H. HULHUL; M & T. NAIKADUGU; M'. PIWALI TILVAN; O. ANASORISIA; P BUGRA, GANDHULI; T'. KUKKA VAVINTA

Polyalthia longifolia (mast tree)= A. & O DABADARU; B. DEBDARU; G. ASHOPALO; H. & M' ASHOK, M. ARANAMARAM; P. DEVIDARI; T NETTILINGAM

Polyanthes tuberosa (tuberose)=A, B & O. RAJANI-GANDHA; H. & P. GUL-SHABO; M'. GULCHHADI; T NILASAMPANGI; T'. SUKANDHARAJI

Polygonum sp.=A. BIHLONGONI; B PANI-MARICH; M MOTHALA-MOOKA, O. MUTHI SAGA; P. NARRI; T. AATALARIE

Portulaca oleracea (purslane) = A. HANHTHENGIA; B. NUNIA-SAK; G LONI; H. & P. KULFA-SAG; M KARI-CHEERA; M'. GHOL; O. BALBALUA; T. KARIKEERAI; T'. PEDDAPAVILIKURA

Pothos scandens=A. HATI LOTA; G. MOTO-PIPAR; M. ANAPPARUVA; M' ANJAN VEL; O. GAJA PIPALI; P. GAZPIPAL

Prosopis spicigera=A. SOMIDH; B., H., M'. & O SHOMI; G. KANDOO; M. PARAMPU; P. JAND; T. PERUMBAI; T'. JAMBI.

Psidium guayava (guava) = A. MODHURI-AM, B. PAYARA, G JAMFAL; H. & P. AMRUD, M PERAKKA, M'. PERU; O PIJULI, T. KOYYA, T'. JAMA

Pterospermum acerifolium = A KONOK-CHAMPA; B MOOCH-KANDA; H KANAK CHAMPA, M' MUCH KUND; O MOOCHKUNDA; T VENNANGU

Punica granatum (pomegranate)= A. & B. DALIM; G. DADAM; H & P. ANAR; M MATALAM; M' DALIMB; O DALIMBA; T. MADULAM

Quamoclit pinnata=A. KUNJA-LOTA. B KUNJA-LATA, TORULATA, H & P. KAMLATA, M'. GANESH PUSHPA, O. KUNJALATA

Quisqualis indica (Rangoon creeper) =A. MADHABI-LOTA; B SANDHYA MALATI; G BARMA SINIVEL; H & P. LAL-MALTI; M' LAL CHAMELI O MODHU MALATI, T RANGOON MALLI

Raphanus sativus (radish)=A, B., M' & O MULA, H. & P. MULI, M. MULLANKI; T. & T' MULLANGI

Rauwolfia serpentina=A. CHANDO' B. CHANDRA, SARPAGANDHA; G SARPA GANDHA; H & P. SARP GAND, CHOTA CHAND; M AMALPORIYAN, M'. SARPA-GANDH; O PATALA GARUDA

Ricinus communis (castor)=A. ERI GOCH; B & P. ARANDA; G ERANDI; H. RENDI; M. & T AVANAKKU; M'. ERAND; O JADA: P. RENDI, ARANDA; T'. AMIDAMU

Rumex vesicarius (sorrel) = A CHUKA-SAK; B. CHUKA-PALANG' H. KHATTA PALAK; M'. CHUKA; O PALANGA; P. KHATTA-MITHA

Saccharum officinarum (sugarcane)= A. KUNHIAR; B. & H AKH; G SHERDE M. & T. KARIMPU; M'. USA; O. AKHU; P. GUNNA; T CHERUKU

Saccharum spontaneum=A. KANIDBON; B KASH; G. & H. KANS; M. NAINKANA; M'. BAGBERI; O. KASHATANDI; P. KAHI

Sansevieria roxburghiana (bowstring hemp)=A. GUMUNI; B. MURGA, MURVA; H. MARUL; M. PAMPINPOLA; O. MURUGA; T. MARUL

Santalum album (sandalwood)=A., B., H., M'. & P. CHANDAN; G. SUKHADA; M. & T. CHANNANA-MARAM, O. CHANDANA; T'. CHAN-DANAMU

Sapindus mukorossi & S. trifoliata (soap-nut)=A MONICHAL, HAITA GUTI; B., H., M'. & P. RITHA; G. ARITHA; M. URVANJI; O. RITHA, MUKTAMANJI; T. PONNANKOTTAI, T'. KUNKUDU

Saraca indica=A., B. & P. ASOK; G. ASUPALA; H. SEETA-ASOK; M. & T. ASOKAM; M'. SITECHA ASHOK, O. ASOKA

Sesamum indicum (gingelly) = A. TISI, B., H., M'. & P. TIL; G. MITHO-TEL; M. & T. ELLU; O. KHASA, RASHI; T'. NUVVULU

Sesbania grandiflora=A. & B. BAK-PHUL; G. AGATHIO; H. & P. AGAST; M. AGATHI; M'. AGASTA; O. AGASTI; T. AGATHYKKEERAI; T'. AVISI

Sesbania sesban = A. JOYANTI; B. JAINTI; G. BAYSANGANI; H. & P. JAINT; M. SHEMPA; M'. SEVARI; O. JAYANTI; T. SITHAGATHI

Setaria italica (Italian millet)=A. KONI-DHAN; B. KAUN; G. KANG; H. CHEENA, KAUNI; M. NAVANA; M'. RALE; O. TANGUN; P. KANGNI; T. TENNAI; T' KORRA, KORALU

Shorea robusta = A., B., H. & P. SAL; G. RAL; M. MARAMARAM; M'. SHALA, RALVRIKSHA; O. SALA; T. SHALAM

Sida cordifolia = A. BARIALA; B. BERELA; G. JANGLI-METHI; H. BARIARA; M. KURUMTHOTTI; M'. CHIKANA; O. BISIRIPI; P. KHAR-ENTI; T. KARUMTHOTTEE; T'. CHIRUBENDA

Smilax macrophylla (Indian sarsa-parilla)=A. HASTIKARNA LOTA; B. KUMARIKA; H. CHOBCHINI; M'. GHOT VEL; O. KUMBHATUA, KUMA-RIKA; P. USHBA

Solanum ferox=A. BON BENGENA; B. RAM-BEGOON; M. ANACHUCHUNTA; M'. BHAJICHE WANGE; O. BHEJI BAIGANA; T. ANAICHUNDAI; T'. MULAKA

Solanum indicum=A. BHEKURI-GOCH; B. BRIHATI; G. UBHIRINGANI; H. BIRHATTA; M. KATTUCHUNDA; M'. DORLI; O. KANTARA; P. BARI KANDIARI

Solanum melongena (brinjal) = A. BENGENA; B. BEGOON; G. & O. BAIGANA; H. BAIGON; M. VAZHU-THANA; M'. WANGE; P. BENGAN; T. KATHTHIRI; T'. VANGA

Solanum nigrum (black nightshade) = A. POK-MOU; B. GURKI, G. PILUDU, H. GURKAMAI, M. MULA-GUTHAKKALI; M'. KANGANI; O. NUNNUNIA; P. MAKO; T. MANA-THAKKALI; T'. KAMANCHICHETTU

Solanum tuberosum (potato)=A., B., H., O. & P. ALOO; G. PAPETA; M. & T. URULAKKIZHANGU; M'. BATATA; T'. URULAGADDA

Solanum xanthocarpum=A. KANTA-KARI; B. KANTIKARI; G. BHOYA-RINGANI; H. KATELI, KATILA; M. KANDAKARYCHUNDA; M'. KATERIN-GANI; O ANKARANTI; P. KANDIALI; T. KANDANKATHTHIRI; T'. NELA-VAKUDU

Sorghum vulgare (great millet)=A. JOU-DHAN; B. & G. JUAR; H. & P. JOWAR; M. & T. CHOLAM; M'. JAWAR; O. BAJARA

Sterculia foetida=A. BAN-BADAM; B., H., M'. & P. JANGLI-BADAM; G. NARKYA-UDA; M. ANATH-THONDI; O. JANGALI BADAM; T. PAEMARAM; T'. GUTTAPU BADAMU

Syzygium aromaticum (clove) = A., H. & P. LAUNG; B LAVANGA; G. LAVANG; M. GRAAMPU; M'. LAWANG; O. LABANGA

Syzygium cumini=A. JAMU; B. KALA-JAM; G. JAMBUDO; H. & P. JAMAN; M. & T. NAAVAL; M'. JAMBUL; O. JAMUKOLI

Syzygium jambos (rose apple) = A. GOLAPI-JAMU; B GOLAP-JAM; H. & P. GULAB-JAMAN; M. PANINIR-CHAMPA; M'. GULAB JAMB; O. GOLAP JAMU; T. NAAVAL; T'. NEEREDU

Syzygium malaccense (malay apple) =A. PANI-JAMU; B. JAMRUL; H. MALAY JAMAN; M'. SAFED JAMB; P. MALAY KA SEB

Tagetes patula (marigold)=A. NARJI-PHUL; B. & H. GENDA; M'. GULJAPHIRI; O. GENDU; P. GENDA, GUTTA

Tamarindus indica (tamarind) = A. TETELI; B. TENTUL; G. AMLI; H. & P. IMLI; M. & T. PULI; M'. CHINCH; O. KAINYA, TENTULI; T'. CHINTHA

Tamarix dioica=A. JHAU BON; B. & H. BON-JHAU; M'. JAO; O. DISHI-JHAUN, THARTHARI; P. PILCHI

Tectona grandis (teak)=A. & B. SHEGOON; G. & H. SHAGWAN; M. & T. THEKKU; M'. SAG; O. SAGUAN; P. SAGWAN; T'. TEKU

Tephrosia purpurea (wild indigo)= A. BON-NIL; B. & H. JANGLI-NIL; G. JHILA; M. KOZHINGIL; M'. SHARAPUNKHA; O. BANA NILA; P. JHANA; T. KOLINGI; T'. VEMPALI

Terminalia arjuna=A. ARJUN-GOCH; B. & H. ARJUN; G. SAJADAN; M. VELLI-LAVU; M' ARJUN-SADADA; O. ARJUNA; P. ARJAN; T MARUTHU; T'. TELLA MADOI

Terminalia belerica (beleric myrobalan)=A. BHOMRA-GUTI, B. & P. BAHERA; G BERANG; H BHAIRAH; M. & T. THANNIKKAI; M'. BEHADA; O. BAHADA

Terminalia catappa (country almond)=A. BADAM-GOCH; B., G., H., M'., O. & P. DESHI-BADAM; M. ADAMARAM; T. NATTUVADUMAI, T'. BADAMI

Terminalia chebula (chebulic myrobalan)=A. SHILIKHA; B. HARITAKI; G. PILO-HARDE; H. & P. HARARA, M. & T. KADUKKAI; M'. HIRDA; O. HARIDA; T'. KARAKA

Thespesia populnea (portia tree)= B. PARAS; G. PARUSA-PIPALO; H. & P. PARAS-PIPAL; M. & T. POOVARASU; M'. BHENDICHA JHAR; O. HABALI; T'. GANGARAVI

Thevetia neriifolia (yellow oleander) = A KARABI; B. KALKE-PHUL; G, H. & P PILA-KANER; M. & T. SIVANARALI; M'. PIWALA KANHER; O. KANIARA, KONYAR PHULA; T'. PACHCHAGANPERU

Tinospora cordifolia=A. AMOR-LOTA, AMOI-LOTA; B. GULANCHA; G GADO, H. GURCHA; M AMRITHU; M'. GUL-VEL, O. GULUCHI; P. GALO; T. SINDHILKODI; T'. TIPPATIGE

Tragia involucrata (nettle) = A. CHORAT; B. BICHUTI; H. & P. BARHANTA; M. CHORIYANAM; M'. KHAJAKOLTI; O. BICHHUATI; T KANJURI; T'. DULAGONDI

Trapa bispinosa (water chestnut)= A. SHINGORI; B PANI-PHAL; G. SHENGODA; H. & P. SINGARHA; M. KARIMPOLA; M'. SHINGADA; O. SINGADA; T. SINGARAKOTTAI; T'. KUBYAKAM

Trewia nudiflora=A. BHELKORA; B. PITULI; H. BHILLAURA; M. THAVALA; M'. PITARI; O. JANDAKHAI, PANIGAMBHAR; P. TUMARI, KHAMARA; T. AATTARASU

Tribulus terrestris = B. GOKHRIKANTA; G. GOKHARU; H. GOKHRU; M. NERUNJIL; M'. KATE GOKHRU; O. GOKHARA; P. BHAKHRA; T. NERINJI; T'. PALLERU

Trichosanthes anguina (snake gourd)=A. DHUNDULI; B. CHICHINGA; G. PADAVALI; H. CHACHINDA; M. PADAVALAM; M'. PADVAL; O. CHHACHINDRA; P. PAROL; T. PUDALAI; T'. POTLA

Trichosanthes dioica = A. & B. PATAL; H. & P. PARWAL; M. PATOLAM; G. & M'. PARWAR; O. PATALA, T. KOMBUPPUDALAI; T'. KOMMUPOTLA

Trigonella foenum-graecum = A. MITHI-GUTI; B., G., H., O., M'. & P. METHI; M. VENTHIAM; T. VENDAYAM

Triticum sativum (wheat) = A. GHENHU; B. GOM; G. GAHUN; H. & P. GEHUN; M. KOTHAMPU; M'. GAHU; O. GAHAMA; T. GHODUMAI; T'. GOTHI, GODUMULU

Typha elephantina (bulrush or elephant grass)=B. HOGLA; G. GHABAJARIN; H. PATER; M'. PAN KANIS; O. HAUDAGHASA, HOGOLA; P. PATIRA; T. CHAMBU

Typhonium trilobatum = A. SAMAKACHU; B. GHET-KACHU; M. CHENA, T. KARUNKARUNAI, ANAIKKORAI; T'. JAMMUGADDI

Urena lobata = A. BON-AGARA; B. BAN-OKRA; H & P. BACHATA; M. OORPUM; M'. VAN-BHENDI; O. JATJATIA; T. OTTATTI

Utricularia sp. = B. JHANJI; M. MULLANPAYAL, KALAKKANNAN; M'. GELYACHI VANASPATI; O. BHATUDIA DALA

Vanda roxburghii (orchid) = A. KOPOU-PHUL; B., H. & P. RASNA; G. RASNA-NAI; M. MARAVAZHA; M'. BANDE; O RASHNA, MADANGA

Vangueria spinosa = A. KOTKORA, MOYEN-TENGA; B. MOYENA; H. MOINA; M'. ALU; O. GURBELI; T. MANAKKARAI; T'. SEGAGADDA

Vernonia cineria=B. KUKSHIM; G. SADORI· H & M' [illegible]

[illegible] ...ADAL; [illegible] . GARITIKAMMA

Vigna sinensis=A. NESERA-MAH; B. BARBATI; H. BORA; M'. CHAVLI; O. BARGADA; P. RAUNG; T. THATTAPAYERU; T'. ALACHANDALU

Vinca rosea (periwinkle)=A. & B. NAYANTARA; H. SADA-BAHAR; M. KASITHUMPA; M' SADAPHULI; O. SADABIHARI; P. RATTAN JOT

Viscum monoicum (mistletoe) = A. ROGHUMALA; B. BANDA; H. & P. BHANGRA, BANDA; M. ITHTHIL; M'. JALUNDAR; O. MALANGA; T. OTTU

Vitis trifolia = B. AMAL-LATA; G. KHAT-KHATUMBO; H. & P. AMAL-BEL; M. SORIVALLI; M'. AMBAT-VEL; O. AMARLATA

Vitis vinifera (grape vine) = A., B., H. & P. ANGOOR; G. MUDRAKA; M. & T. MUNTHIRYVALLY; M'. DRAKSHA-VEL; O. ANGURA; T'. DRAKSHA

Wedelia calendulacea = A. BHIMRAJ; B BHIMRAJ, BHRINGARAJ; G., H. & P. BHANGRA; M. PEE-KAYYANNYAM; M'. PIVALA-BHANGRA; O. BHRUNGA-RAJA

Withania somnifera = A. LAKHANA; B ASWAGANDHA; G. ASUNDHA; H. & P. ASGANDH; M. & T. AMUK-KIRAM; M'. ASKANDH; O. AJA-GANDHA; T'. ASVAGANDHI

Wrightia tomentosa = A. DUDHKHO-ROI; B. INDRAJOB; G., H. & P. DUDHI; M. & T. NILAM-PALA; M'. KALA-INDERJAW; O. PHAOKURNI; T'. PALA

Xanthium strumarium (cockle bur) = A. AGARA; H. & H. OKRA; G. GADIYAN; M'. SHANKESHVAR, O. CHOTA GOGHURU; P. GOKHRU KALAN; T. MARLUMUTTA; T'. MARU-LAMATHANGI

Xanthophyllum budrunga = A BROJO-NALI; B. BAZINALI; H. BADRANG; M. KATTUMURIKKU; M'. BUDRANJ; T. IRATCHAI; T'. BACHAMAM

Zea mays (Indian corn or maize) = A. MAKOI-JOHA; B. BHUTTA; G., H. & P. MAKAI; M. & T. CHOLAM; M'. & O. MAKA; T'. MOHKA-JONNA

Zingiber officinale (ginger) = A., B & O. ADA; G. ADHU; H. ADRAK; M. INCHI; M'. ALE; P. ADARAK; T. INJI; T'. ALLAM

Zizyphus jujuba (Indian plum) = A. BAGARI; B. KUL; G. BORADI; H. & P. BER; M. & T. ELANTHAI, M'. BOR; O. BARKOLI, T'. REGU

Zizyphus oenoplia = A. BAN-BAGARI; B. SHIAKUL; M. THODALI; M'. BURGI; O BHUINKOLI; P. MAKOH; T. SOORAI; T'. BANKA

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